MARS

THE ROLE OF AN ARCHITECT IN THE SPACE INDUSTRY

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ARCH 5200-02 | ARCH 5210-2
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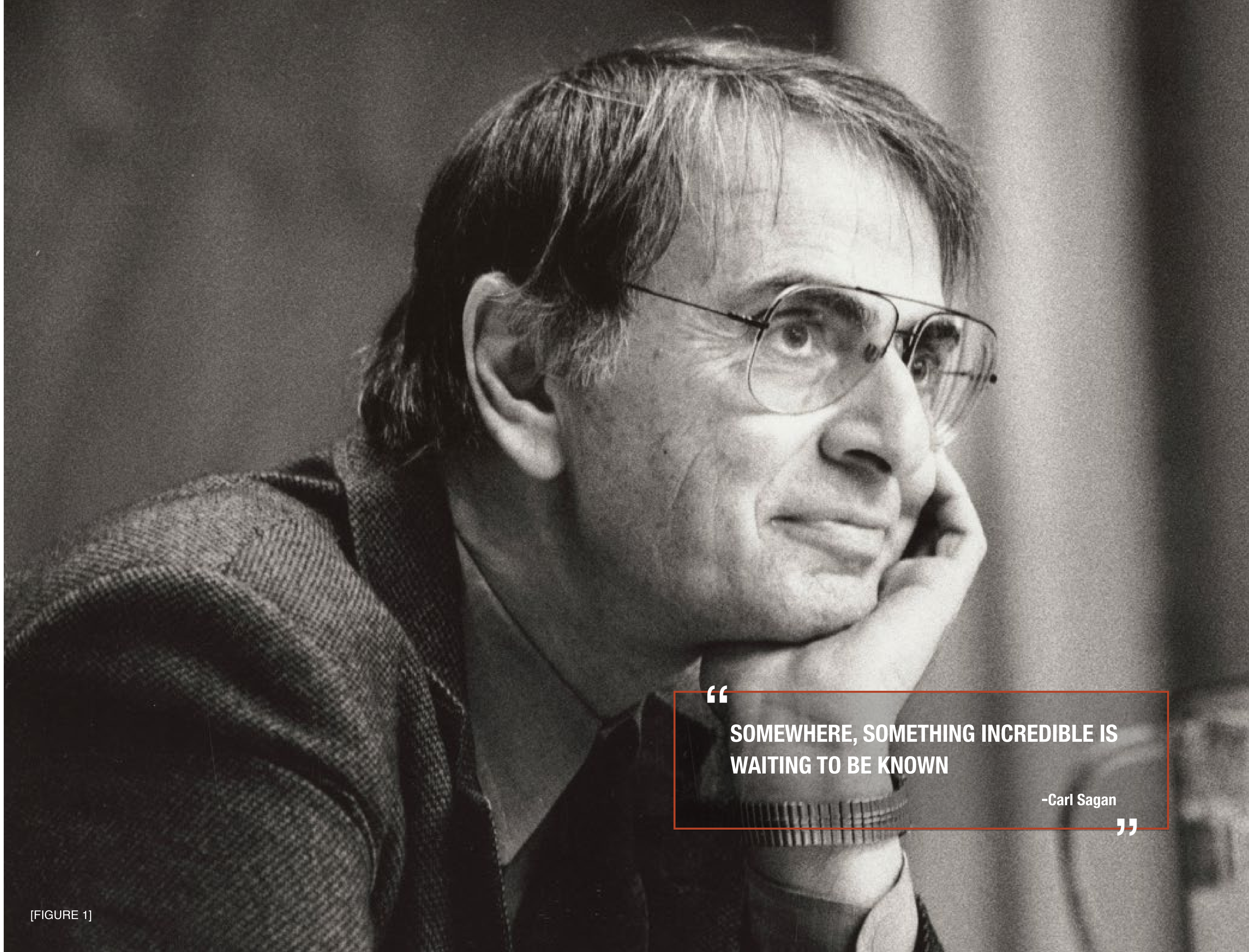
“
SOMEWHERE, SOMETHING INCREDIBLE IS WAITING TO BE KNOWN
-Carl Sagan
”

[FIGURE 1]

PERSONAL STORY: THESIS MOTIVE

One of my favorite quotes is by Carl Sagan when he said, “Somewhere, something incredible is waiting to be known,” This line is what sparked my curiosity in science and lead me thinking about the idea of “Egocentrism.” One of the characteristics that is inherent in human beings is the belief that we are unique, so we have rooted the entire theory of existence around our own, and nothing else. We’re the beginning and the end of the universe, and there’s nothing as significant as we are. There is no logical explanation to justify this belief; we simply don’t know enough.

This belief is deep-rooted in the way we exist. It’s ingrained in us and in the way we think and behave. For instance, the entire existence of some of the main religions revolves around the idea that the Universe was created by God, for us. In literature, we use Greek and Roman gods as a metaphor to idealize ourselves from a distance, so we don’t have to admit that we’re the ones who long for that status. In Art, during the renascence, Michelangelo painted the “Creation of Adam” where God breathes life into Adam. In this painting, Michelangelo was expressing that the Divine Gift doesn’t come from a higher power, but it comes from within us. A common theme through of all these forms of expression and ideas is us, humankind. The egocentric belief is deeply rooted in all of us; we are the center of the universe.

But I always wondered, what if we’re wrong? What if there’s something beyond our existence as conscious beings? What if there is something out there…. what if life exists beyond Earth? That is why we should explore space, and why I’m interested in the colonization of Mars. My passion for architecture and curiosity in understanding our place in the universe has inspired me to explore the role of an architect in the space industry as my thesis topic.

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INTRODUCTION

SOL I

[FIGURE 2]

SOL I:1 THESIS OBJECTIVE

What and how will we define the role of an architect in an interdisciplinary industry, the Space Industry? This thesis is not solving a particular problem by any means, but it's an investigation in understanding the value an architect can bring to the Space Industry through the design and study of building materials and psychological influence of confined and extreme environments have on people. Architects design environments that affect the physical and psychological well-being of individuals; these spaces shape the way we feel, think and behave. It's a significant role that will add a valuable contribution to the process of creating the new world on Mars.

SOL I:2 ABSTRACT | MARS

For all human history, our ancestors have looked to the stars to find meaning and understanding of ourselves and our world. Our ancestors found no distinction between earth and the heavens; the sky was an extension of our existence in which was reflected in science, religion, philosophy, art and literature. *(See history of astronomy for further explanation and examples)*

As we look to the stars today, we find ourselves questioning our place in the universe. Our curious nature to explore the unknown is a basic human instinct that seeks a better understanding of the world. Our desire to seek knowledge has placed us in front of a new challenge, a new world; planet Mars.

The question of whether to take on Mars as the new destination for humankind is not only a goal but also a reflection of the pioneering spirit of our society. Mars is the next logical step for all humanity to explore and make it the new home.

> **FOR THE SCIENCE, FOR THE CHALLENGE, FRO THE FUTURE; THAT'S WHY WE SHOULD GO TO MARS.**
>
> -Robert Zubrin

[FIGURE 3]

SOL I:3 WHY MARS

As we expand our knowledge of the solar system, Mars is a valuable destination for humanity's search to understand its place in the universe. Robert Zubrin, an aerospace engineer, author, and founder of Mars Society wrote in his book The Case for Mars, "We now know for certain that Mars was once a warm and wet planet, possessing not only ponds and streams but oceans of water on its surface, and continued to have an active hydrosphere for a period on the order of a billion years -- a span five times as long as the time it took for life to appear on Earth after there was liquid water here. Thus, if the theory is correct that life is a natural phenomenon emerging from chemistry wherever there is liquid water, various minerals, and a sufficient period of time, then life must have appeared on Mars" (Zubrin. XI-XII). Mars is comparable to Earth's formation and evolution, which will help us learn about our own planet's history and future.

The Red planet is where the action will be in the next century. Mars is the only planet within our solar system where there is a significant chance of finding past and possibly present life. Its unexplored mountains, ice fields, and vast surface may hold an unbelievable amount of riches and resources for future humanity. Moreover, it may hold answers for some of the deepest philosophical questions that we have been pondering for centuries. Mars has the possibility of offering us a new frontier, and similar to the Americas, a new civilization that will provide an engine of progress for all of humanity. But all that Mars holds will forever remain beyond our grasp unless and until we walk on its surface (Zubrin, pg1).

SOL I:4 FORWARD MESSAGE

“Message to Mars

My name is Arthur Clarke, and I am speaking to you from the island of Sri Lanka, once known as Ceylon, in the Indian Ocean, Planet Earth. It is early spring in the year 1993, but this message is intended for the future. I am addressing men and women__ perhaps some of you already born__ who will listen to these words when they are living on Mars.

Note:
This forward message is from the book “The Case for Mars” .

As we approach the new millennium, there is great interest in the planet which may be the first real home for mankind beyond the mother world. During my lifetime, I have been lucky enough to see our knowledge of Mars advanced from almost complete ignorance_ worse than that, misleading fantasy__ to a real understanding of its geography and climate. Certainly, we are still very ignorant in many areas, and lack knowledge which you take for granted. But now we have accurate maps of your wonderful world, and can imagine how it might be modified__ terraformed__ to make it near to the heart’s desire. Perhaps you are already engaged upon that centuries_ long process.

There is a link between Mars and my present home….At the beginning of this century, an amateur astronomer named Percy Molesworth was living here in Ceylon. He spent much time observing Mars, and now there is a huge crater, 175 kilometers wide, named after him in your southern hemisphere. In my book I’ve imagined how a New Martian astronomer might one day look back at his ancestral world, to try and see the little island from which Molesworth_ and I _ often gazed up at your planet.

There was a time, soon after the first landing on the Moon in 1969, when we were optimistic enough to imagine that we might have reached Mars by the 1990s…Watching the Earth in transit across the face of the Sun on May 11_ 1984! Well, there was no one on Mars then to watch that event_ but it will happen again on November 10, 2084. By that time, I hope that Many eyes will be looking like a tiny, perfectly circular sunspot. And I’ve suggested that we should signal to you then with powerful lasers, so that you will see a star beaming a message to you from the very face of the sun.

I too salute to you across the gulf of space_ as I send my greetings and good wishes from the closing decade of the century in which mankind first became a space-faring species, and set forth on a journey that can never end, so long as the universe endures.”

(Arthur C. Clarke)

1 March 1996

FACTS & HISTORY OF SPACE

SOL II

II 1:1 HISTORY OF ASTRONOMY

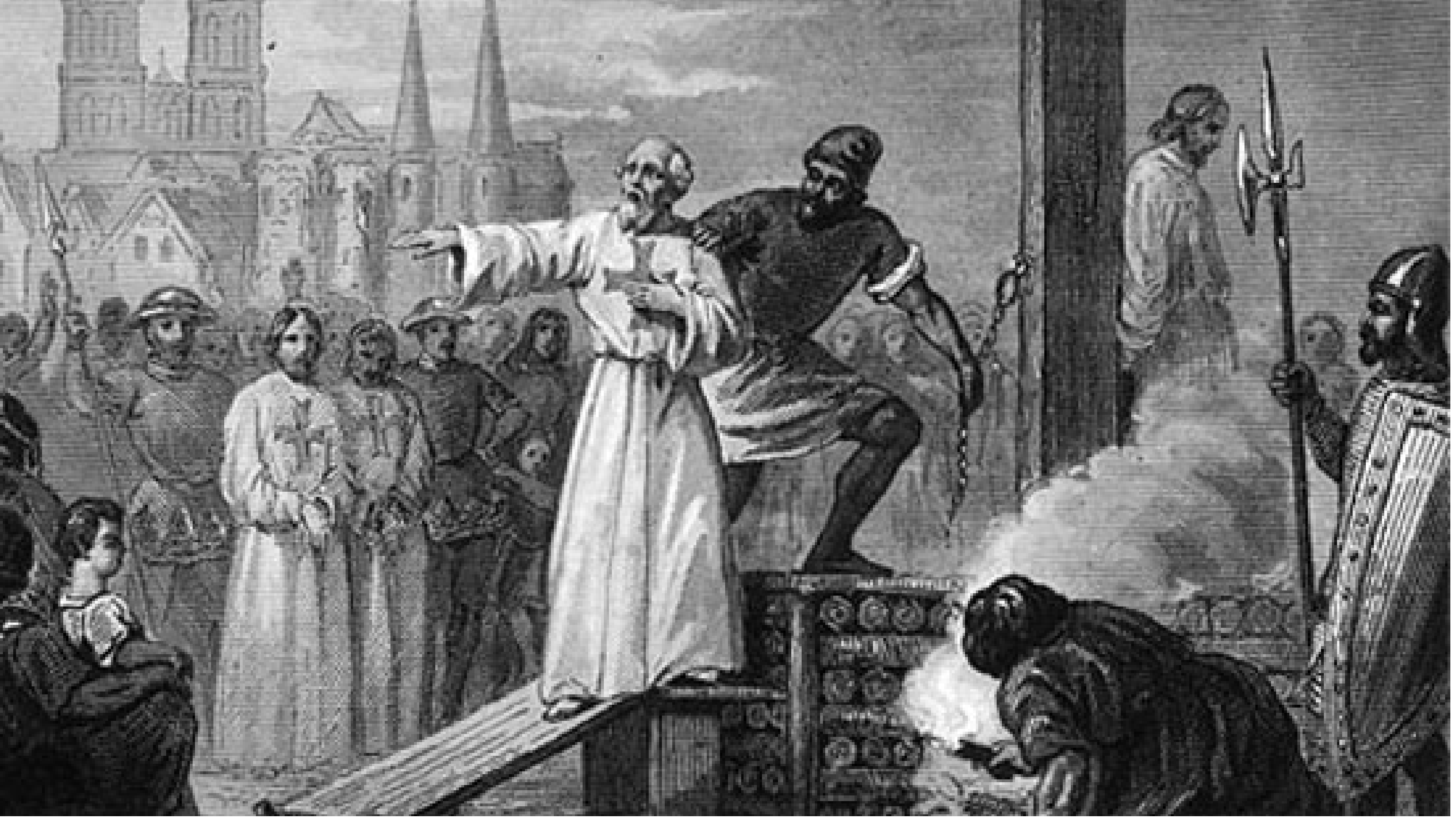
ASTRONOMY

The history of space exploration and humankind's fascination with the universe dates back thousands of years. Ancient Babylonia, a civilization that flourished in what is now modern-day Iraq, developed an advanced system of astronomy to study the movement of the sun and the stars for hundreds of years. This sophisticated system gave planets a status of gods, which they worshiped (Mesopotamian Astronomy, explorable).

In one of the earliest civilizations, ancient Egyptian, looked up to the heavens to understand and find meaning in their world. As a result, the pattern and behaviors of the sky led them to create myths to explain the astronomical phenomena. The pyramids had a certain astronomical orientation, and their gods and goddesses were represented by physical astronomical bodies in the sky. For instance, Osiris, the god of death, rebirth, and the afterlife was represented in the constellation Orion. The sky goddess, Nut, giving birth to the sun "Go Ra" was represented by the Milky Way Galaxy (Lockyer, Ancient Egyptian Astronomy, starteachastronomy).

The Italian astronomer Galileo Galilei publicized the fact that other astronomical bodies were revolving around something other than Earth, which supported Copernicus's model that the sun is the center of the universe. Galileo also was the first person to see the valleys of the moon and the stars through a telescope; a telescope in which sparked scientist's fascination with planet Mars (Burnham, Great Astronomers, starteachastronomy).

For centuries, humans observed Mars. This opened many intellectual vistas for scientists that revealed the human mind could explore the cosmos and understand the complexity of the universe. It has been a long journey to reach what is now an exciting era of space exploration – an era that didn't start in the twentieth century, but many centuries before.



A STORY OF SACRIFICE

It began with a story of sacrifice, the story of the great Italian scientist, Giordano Bruno, which is worthy of our acknowledgment. In 1600, Giordano Bruno was taken from his cell and dragged naked through the streets of Rome. He was led to the square of the city, the place of execution where one of his killers held a portrait of Jesus Christ in front him and demanded repentance. Bruno angrily turned his face away; at that moment one of the most brilliant minds in human history was burned alive.

Bruno was murdered for questioning and threatening a core belief of Christianity: that Earth is the center of the universe. He stated in a debate and writing that the universe was infinite, and the stars were suns like our own with other planets around them. Therefore, observers on the other planets would see Earth in their sky, their heavens, which means we are the "heavens." Why was astronomy subject to cruel attacks? Why did the church feel threaten by Bruno? The church was threatened, and astronomy was subject to such severe attacks because it challenged the intellectual framework of Christianity and its existence (Zubrin, The case for Mars).

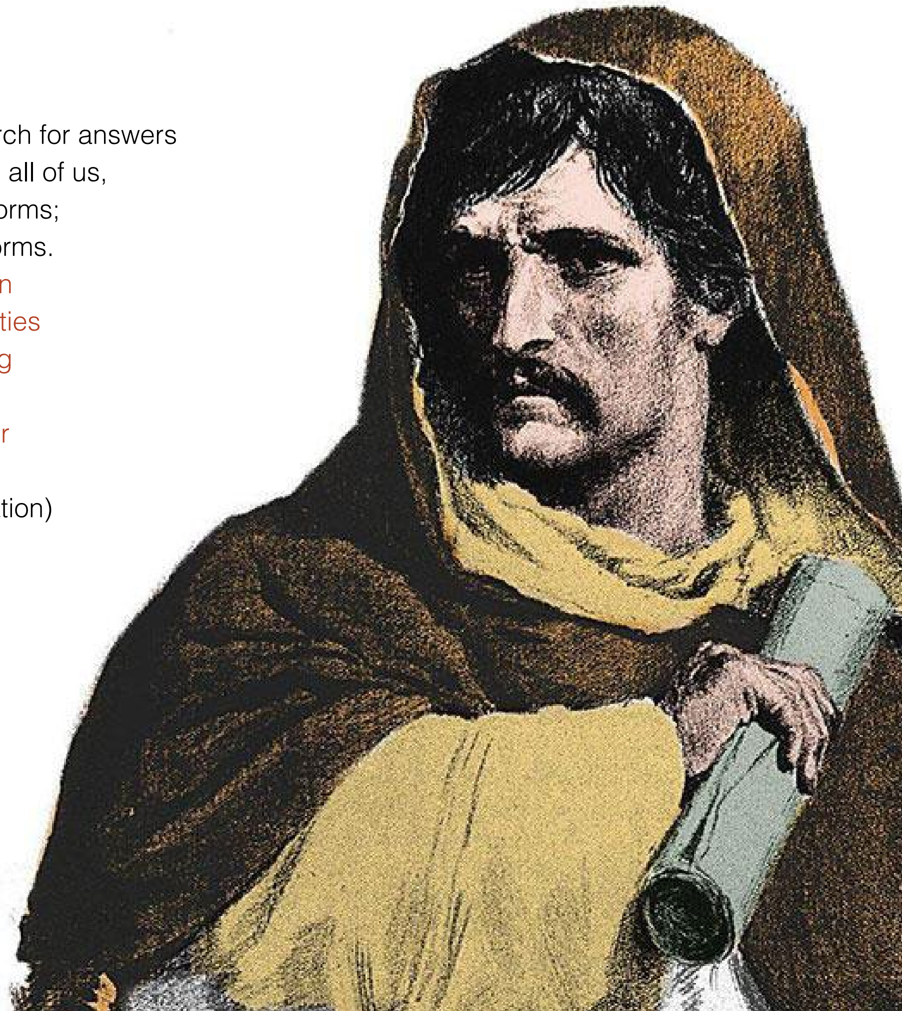
Johannes Kepler, a Platonist wrote, "Geometry is one and eternal, a reflection out of the mind of God. That mankind shares in it is one of the reasons to call man an image of God" (The Scientific Intellectual, Lewis S.Feuer, pg.134). This quote meant that if the human mind is capable of understanding the universe then everything that seems rational to God, it also can be seen rational to the human understanding. In another words, if we think and search for answers, we can find a rational explanation for everything. This is the very thing Bruno died for, and it's the very thing Kepler set out to prove with the help of the planet Mars.

Johannes Kepler (1571-1630, German) was Tycho Brahe's assistant and student. He used the idea of elliptical orbits to describe the motions of the planets, which became known as Kepler's first law.

At the same time Bruno died, Kepler went to work for one of the greatest observational astronomer, Tycho Brahe. After eight years of intense work, Kepler discovered that Mars traveled in an elliptical orbit, with the Sun as the focus of the ellipse. Kepler's study of Mars brought humanity to a new era of our understanding of the universe and the start of space exploration.

Giordano Bruno (1548 – 1600), was an Italian Dominican friar, philosopher, mathematician, poet, and cosmological theorist.

Reflection: Our desire to search for answers is a biological instinct born in all of us, expressedin many different forms; imagination is one of these forms. Imagination and creativity can help us explore new possibilities that will not only solve existing problems but also potential problems we might encounter in our colonization of Mars.
(See Sol 3 for further explanation)



II 1:2 HISTORY OF MODERN SPACE TECHNOLOGY

The history of modern space exploration began in 1957 when the Soviet Union launched the first unmanned mission into space. The Soviet Union launched a satellite called Sputnik 1, which orbited earth successfully for 3 months. This led to the beginning of the “Space Race”. The space race brought a revolution to this industry, which by 1969, led the United States to put the first man on the Moon. These efforts inspired the public and scientific community to further explore space. It sparked a new interest to explore and better understand Mars. While some of the efforts to explore Mars were flybys gathering information, others were long standing orbiters that lasted years over the Red Planet (Howell, A brief history of mars missions, space).

> “The Apollo program involved more than 400,000 engineers and scientists, and technicians from more than 20,000 private companies and universities to reach the achievement of one man walking on the moon.”

> “The essence of collaboration is when the goal itself is greater than the individual.”

HOW COLLABORATION PUT MAN ON THE MOON

The Apollo Program was one of the most challenging and inspiring projects humankind has accomplished; the key to its success was collaboration. The Apollo Program involved more than 400,000 people from different professions, companies and educational institutions to achieve one common goal, to put man on the moon. During an interview, the Chief engineer of the Lunar Module, Owen W. Morris, said, “we get together on a frequent basis, compare notes about what the problems were and what anybody could do to help the situation. And there was a spirit of cooperation pretty much throughout the program. At no point was any team in the dark about what another group was doing, or what support they needed” (Zero Agency, Medium Corporation). Interdisciplinary collaboration is necessary to achieve a daunting task such as putting man on the moon; a goal that is greater than the individual.

The exploration and eventual human travel to Mars is not a new idea, but it is a goal that many people share. The colonization of Mars is a daunting challenge that is far more difficult than going to the moon. However, there is a lesson to be learned from the Apollo program, that it had a greater common goal that inspired an interdisciplinary collaboration. In the case of Mars, the goal itself is greater than all of us. Thus the key ingredient for a successful Mars mission will be interdisciplinary collaboration that involves many people including the expertise of architects. Thus, how do we define the role of an architect in the Outer Space Industry? (See Sol 3 for further explanation)

II 1:3 HISTORY OF MARS MISSIONS

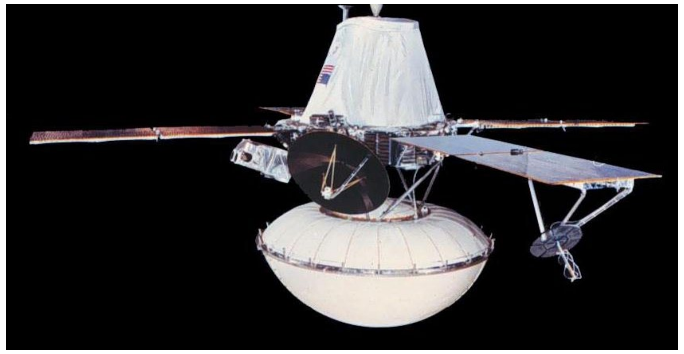
Although the financial and logistical challenges to send manned missions to Mars remain, unmanned missions began in 1960. There have been 55 Mars missions, 26 of those were successful. Currently, there are 13 robots and probes on the surface of Mars, only two of these are still operating. Another 5 operating satellites are orbiting the red planet.

MARINER 4

In 1964, the first Space craft to successfully fly by Mars returned the first pictures of the Martian surface.

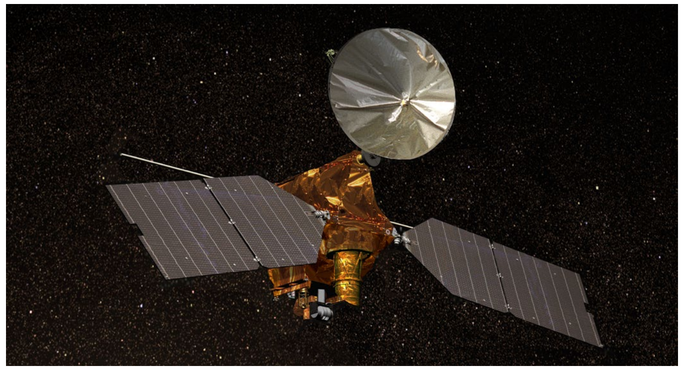
MARINER 9

In 1971, Mariner 9 arrived while the entire planet was covered by a dust storm. It discovered the largest canyon in the solar system, Valles Mariners. Mariner 9 spent about a year orbiting Mars, and returned 7,329 photos.



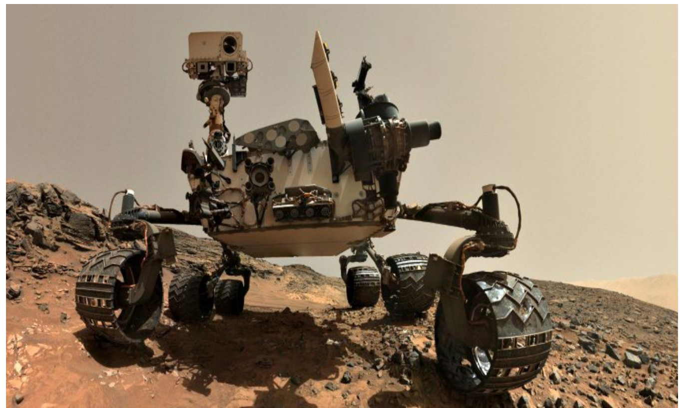
VIKING 1 & 2

In 1975, the U.S. landed the first spacecraft on the Martian surface. It was the first extended exploration returning images and other information of the Martian surface.



MARS ODYSSEY

In 2001, Mars Odyssey reached the Martian surface, and continues to conduct its extended mission, making it the longest-serving spacecraft on Mars. It has returned 350,000 images and mapped global distributions of several elements.



CURIOSITY ROVER

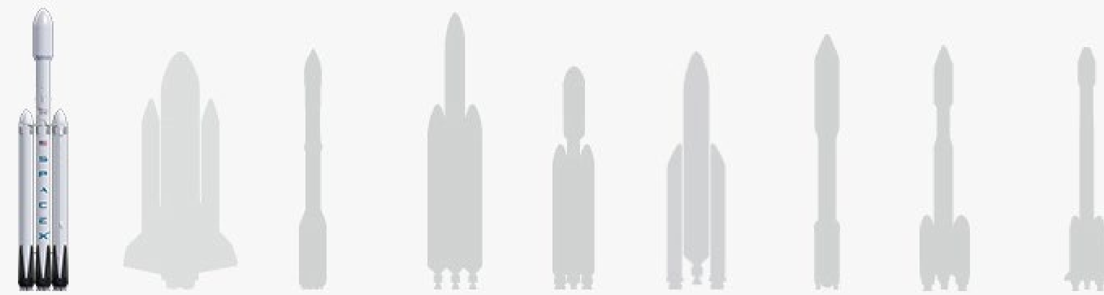
In 2012, Curiosity successfully landed on the Martian surface exploring Gale Carter as part of NASA's Mars Science Laboratory mission. The goal of the rover is to find if Mars has supported life, and study climate and geology of Mars.

II 1:4 FUTURE OF MARS EXPLORATION

In an era where governments and private companies are competing, the space industry is making a significant technological progress. NASA is working on a long-term plan to send manned- missions to Mars over the next 2 decades. The goal of this program is to build on discoveries from past missions and test new technologies. Other governments such as China and Russia have announced similar plans to take place between 2040 and 2060.

In 2016, SapceX founder, Elon Musk, announced their intention to send the next-generation of the Dragon spacecraft to Mars every two years, starting in 2018. SpaceX plans to send a manned-mission to Mars in 2026 and plans to have one million people living on the Red Planet by the next century. These efforts are taking place with the new development of the largest space vehicle called, Interplanetary Transport System (ITS). The goal of these ambitious efforts is to establish a growing self-sustaining colony on Mars (Hesse, We're going to the Red Planet, digitalrends).

VEHICLE PERFORMANCE

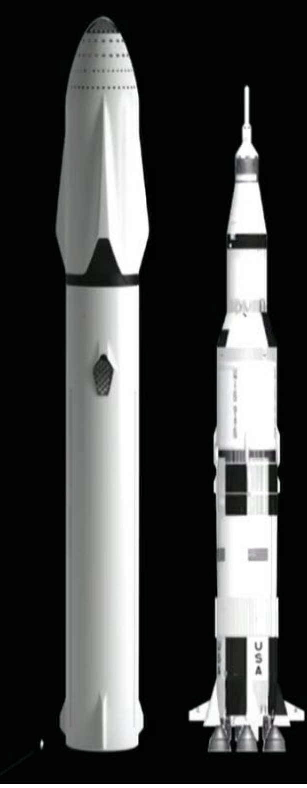


LAUNCH VEHICLE	FALCON HEAVY	SPACE SHUTTLE	PROTON M	DELTA IV HEAVY	TITAN IV- B	ARIANE 5 ES	ATLAS V 551	JAPAN H2B	CHINA LM3B
PAYLOAD TO LOW EARTH ORBIT (LEO)	54,400 KG	24,000 KG	22,560 KG	22,650 KG	21,680 KG	20,000 KG	18,510 KG	16,500 KG	11,200 KG

RED DRAGON

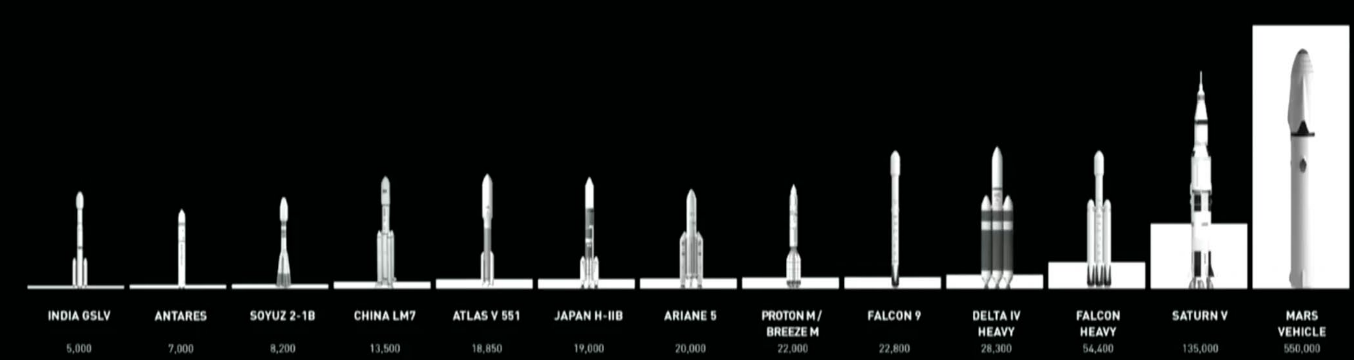
In 2018, SpaceX with the help of NASA is planning to launch an unmanned mission to Mars using Falcon Heavy rockets. The objective of this mission is to test techniques and technology to enter the Martian atmosphere with equipment a human crew could use in the 2026 - manned mission.

	MARS VEHICLE	SATURN V	RATIO
GROSS LIFT-OFF MASS (t)	10,500	3,039	3.5
LIFT-OFF THRUST (MN)	128	35	3.6
LIFT-OFF THRUST (t)	13,033	3,579	3.6
VEHICLE HEIGHT (m)	122	111	1.1
TANK DIAMETER (m)	12	10	1.2
EXPENDABLE LEO PAYLOAD (t)	550	135	4.1
FULLY REUSABLE LEO PAYLOAD (t)	300	-	-



INTERPLANETARY TRANSPORT SYSTEM (ITS)

In 2026 – 28, SpaceX in collaboration with NASA plans to launch the first manned mission to Mars using the "Interplanetary Transport System", which will combine the most powerful rocket with the largest spaceship. This spaceship has a capacity of 500 tons of payload, 4 times more than the biggest spaceship NASA has ever created.



II 1:5 MARS FACTS

DISTANCE

Mars is closest to Earth when it's close to the sunand Earth is farthest from the sun with a distance of 339 million miles.

TEMPERATURE

Earth average temperature is 57 degrees, and Mars average temperature -81 degrees.

ATMOSPHERE

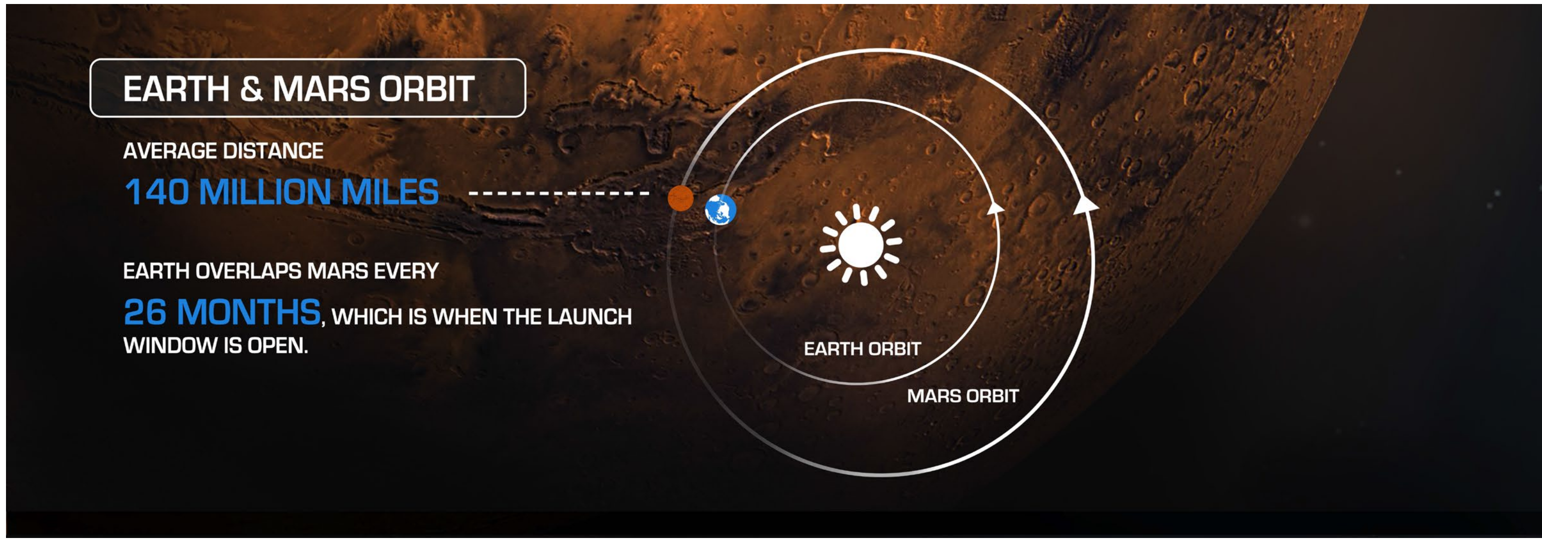
Mars atmosphere is 1% of Earth.

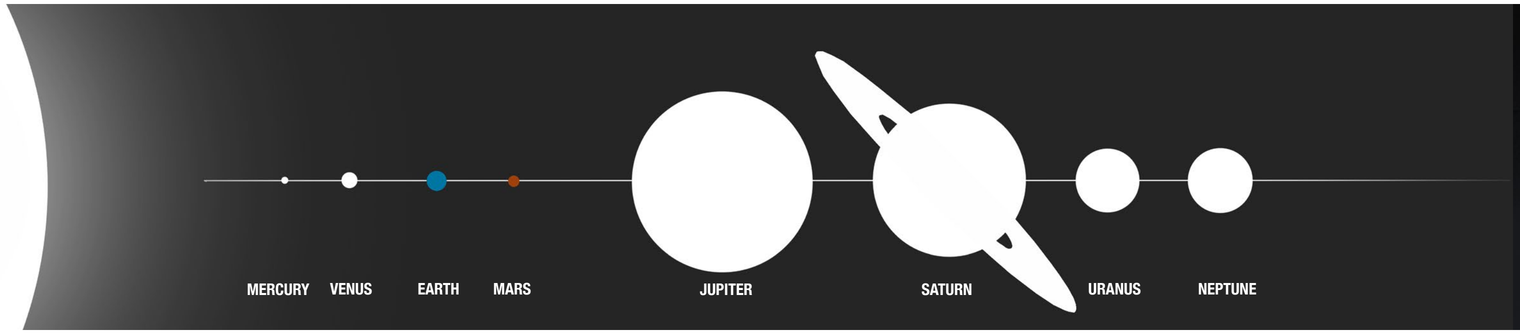
GRAVITY

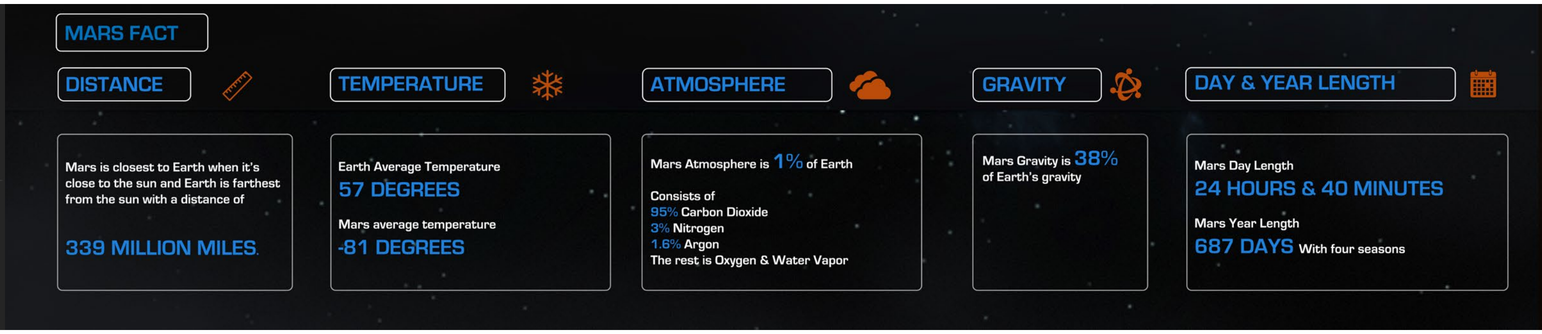
Mars gravity is 38% of Earth's gravity.

DAY AND YEAR LENGTH

Mars day length is 24 hours and 40 minutes. Mars year length 687 days with four seasons.







INVESTIGATION THROUGH RESEARCH

SOL III

III 1:1 JOURNEY TO MARS

Mars is the new destination for humanity's curiosity and scientific discovery. The Red Planet is the closest planet to Earth's conditions, which can help us learn about the past and future of our planet. Scientists have uncovered that Mars had conditions suitable for life in its past. Future missions can answer one of the most fundamental questions - does life exist beyond Earth? (NASA's Journey to Mars, mars.nasa).

III 1:2 CHALLENGES FOR SPACE PIONEERS

A journey to Mars is historic pioneering endeavor. It comes with a great deal of sacrifice and risk - but the journey is worth it. In order to succeed on Mars, self-reliance and increased system reliability is a must. However, there are many physical and psychological challenges to overcome. Solving these problems will enable humans and cargo to Mars to reach efficiently and safely and work productively and collaboratively in a healthy and safe habitation system. Bridging these two categories is the primary logistical challenge facing crewed missions to explore Mars.

III 1:3 PSYCHOLOGICAL CHALLENGES

ISOLATION & CONFINED ENVIROMENT ON MARS

Mars colonists will be the most isolated humans to have ever lived. Due the vast distance between Mars and earth, the shortest communication will take about 10 minutes, making real time interaction with earth impossible. People staying on Mars will be able to interact only with crew members. NASA has been studying the psychological issues among isolated people in confined spaces for decades. In a published paper, NASA Human Research team, Abadie, W.Lloyd, and Shelhamer wrote:

“NASA has learned that behavioral issues among groups of people crammed in a small space over a long time, no matter how well trained they are, inevitable. Expedition crews selected for a stay aboard the space station are carefully chosen, trained, and supported to make sure they can work effectively as a team for six months.Crews for a Mars mission will undergo even more scrutiny and preparation, since they will travel farther and longer than any previous human, being more isolated and confined than we can imagine.

Crews for a Mars mission will undergo even more scrutiny and preparation, since they will travel farther and longer than any previous human, being more isolated and confined than we can imagine. The types of problems people may encounter are a decline in mood, cognition, morale, or interpersonal interaction. People could also develop a sleep disorder because your circadian rhythm might be thrown off due to the 38 extra minutes each day on Mars, or by a small, noisy environment, or the stress of prolonged isolation and confinement. Depression could occur. Fatigue is inevitable given that there will be times with heavy workload and shifting schedules. Still, periods of monotony may lead to boredom rearing its ugly head. Misunderstandings and impaired communications with your team members might impact performance and mission success. A lack of fresh food and mean variety, or deficiency in nutrition, may further contribute to physiological and cognitive decrements. Also, far more autonomy will be required due to the very long communication delays over the vast distances from the space vehicle to Earth. And then there’s the possibility of the third-quarter effect, where morale and motivation decline three-quarters of the way into a mission, regardless of how long the mission lasts. The more confined and isolated humans are, the more likely they are to develop behavioral or cognitive conditions, and psychiatric disorders” (Abadie, W. Lloyd, Shelhamer, The Human Body in Space, NASA).

THE VALUE OF AN ARCHITECT IN THE SPACE INDUSTRY

The exploration of Mars is a terrifying venture, demanding much of both body and mind. Its distance from Earth and harsh environment can push people's minds to the brink of sanity. While engineers and scientists can design functional structures to keep the astronauts' bodies protected from the harsh Martian environment, those confined spaces could make one feel isolated — pushing their mental abilities beyond its limits. This is where the expertise and creativity of an architect would be a very valuable asset in the space industry. Architects design environments that influence not only the physical well-being, but also the psychological well-being of people. Dr. Melanie Dodd, program director of spatial practices at the Central St Martins art school, says, "The impact architecture has on a person's mood is huge. Arguably these are the fundamentals of architecture: not how it looks, but how we feel it, through the way it allows us to act, behave, think and reflect," (Gander, how architecture uses space, light and material to affect your mood, Independent.co.uk). The value of architects lies within their expertise in shaping environments through the use of materials, color, texture and a good spatial understanding that can influence the physical and psychological well-being of people in confined spaces.

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The importance of architecture as a trigger to physical, physiological and psychological well-being is nowadays becoming a topic of significant relevance.

- Dr. Melanie Dodd

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> PEOPLE AUTOMATICALLY ASSOCIATE RED WITH DANGER, WHICH MAKES THEM MORE ALERT AND AWARE.

ARCHITECTURE & HUMAN PSYCHOLOGY

DESIGN EXPERIMENT I

We spend most of our lives inside buildings. Our thoughts and behavior are shaped by these environments. Most likely, these phenomena will have the same influence on the people who will colonize Mars. But how do different spaces influence cognition? How can the color of a space influence the astronaut's mood? How can materials influence the daily lives of astronauts on Mars? In 2009, an experiment conducted by the University of British Columbia and published in Science, looked at how the color of an interior wall can influence people's imagination. The 600 subjects who were tested, performed a variety of basic cognitive tests displayed against red, blue or neutral colored backgrounds, Jonah Lehrer, a science writer at Wired magazines, described the experiment:

"The differences were striking. When people took tests in the red condition – they were surrounded by walls the color of a stop sign – they were much better at skills that required accuracy and attention to detail, such as catching spelling mistakes or keeping random numbers in short-term memory. According to the scientists, this is because people automatically associate red with danger, which makes them more alert and aware.

The color blue, however, carried a completely different set of psychological benefits. While people in the blue group performed worse on short-term memory tasks, they did far better on those requiring some imagination, such as coming up with creative uses for a brick or designing a children's toy out of simple geometric shapes. In fact, subjects in the blue condition generated twice as many "creative outputs" as subjects in the red condition. That's right: the color of a wall doubled our imaginative power.

What accounts for this effect? According to the scientists, the color blue automatically triggers associations with the sky and ocean. We think about expansive horizons and diffuse light, sandy beaches and lazy summer days. This sort of mental relaxation makes it easier for us daydream and think in terms of tangential associations; we're less focused on what's right in front of us and more aware of the possibilities simmering in our imagination." (Lehrer, the psychology of architecture, Wired).

DESIGN EXPERIMENT II

Another experiment conducted by the psychologist Joan Meyers-Levy, at the Carlson school of Management examined the relationship between thinking style and ceiling height. Again, writer Lehrer described the experiment:

"She demonstrated that, when people are in a low-ceilinged room, they are much quicker at solving anagrams involving confinement, such as "bound," "restrained" and "restricted." In contrast, people in high-ceilinged rooms excel at puzzles in which the answer touches on the theme of freedom, such as "liberated" and "unlimited." According to Levy, this is because airy spaces prime us to feel free.

Furthermore, Levy found that rooms with lofty ceilings also lead people to engage in more abstract styles of thinking. Instead of focusing on the particulars of things, they're better able to zoom out and see what those things have in common. (It's the difference between "item-specific" versus "relational" processing.)

Sometimes, of course, we want to focus on the details of an object or problem, in which case a claustrophobic basement is probably ideal. However, when we need to come up with a creative solution, then we should probably seek out a more expansive space. Especially if it has blue walls." (Lehrer, the psychology of architecture, Wired).

It's clear that the way our environment is shaped has a significant influence on the way we feel, think and behave; all necessary for the survival and well-being of astronauts and scientists living on Mars. The key for future for Martian colonists is a collaboration among experts from different professions including architects. Again, the value of architects lies within their expertise in shaping environments through the use of materials, color, texture and a good spatial understanding that can influence the physical and psychological well-being of people in confined spaces.

III 1:4 ANTARCTICA

The age of Antarctic Exploration began in the 19th century, opening a new world of scientific discovery. Long –term stays in extreme environments like Antarctica has helped us have a better understanding of the psychological effects and our own mental abilities. Due to isolation and confinement, Antarctic explorers experienced dramatic psychological effects. For instance, Von Drygalski, captain of the first German expedition (1901–3), wrote:

“There were occasional bouts of depression in the ward room ... From time to time in the course of the winter these symptoms grew worse largely because of the restrictions on movement enforced by the snowstorms and the monotony of the duties” (von Drygalski, The southern ice-continent: The German south polar expedition abroad the Gauss).

The psychological effects during the early Antarctic Exploration exposed crew members to real danger, in some cases resulting in suicide. However, today through an interdisciplinary collaboration among scientists, engineers, psychologists, and architects these effects have less of a pejorative influence on the team who currently reside in Antarctica; largely due to the improved living conditions.

CASE STUDY

Halley VI Polar Research Station

The Halley VI is a British research station located in southern Antarctica. It's one of the most challenging buildings to be ever built in an extreme environment on Earth. The project team director, Peter Ayres wrote:

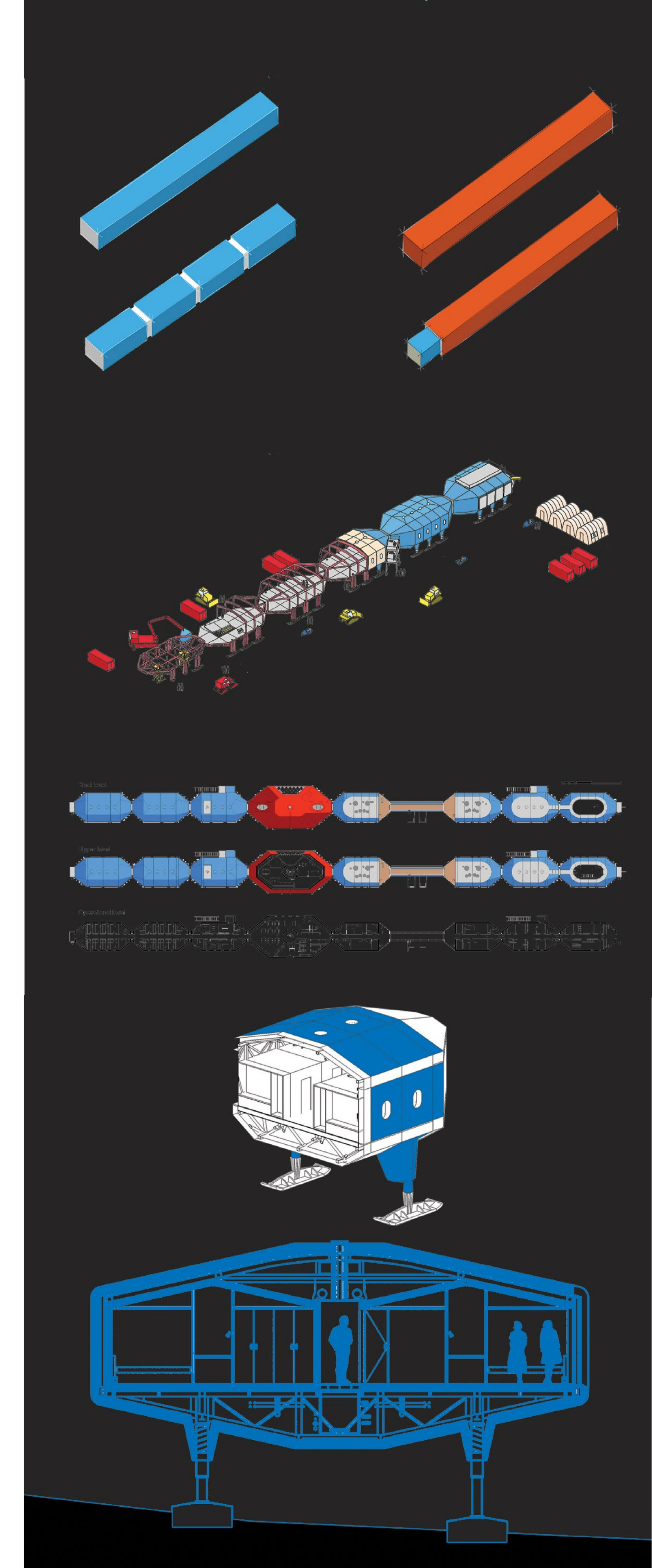
"The world's first fully relocatable, permanently manned Antarctic research station, it redefines polar architecture and engineering.The Halley VI research area is the southernmost Antarctic station operated by BAS and is located on the 150-meter-thick (492-feet-thick) Brunt Ice Shelf, which flows out to sea at an annual rate of 400 meters (1,312 feet). Design principles centered around survivability, maintainability and livability, allowing the station to function reliably and economically as a home for dozens of scientists who will be living there for up to 18 months at a time.

Some of the immense technical challenges involved required considerations of logistics, extreme cold, wind and snow environments, snow accumulation, moving ice, narrow construction windows, environmental protocols and tight financial constraints.

Halley VI's success can be attributed to an intimate collaborative process among AECOM, BAS, Hugh Broughton Architects and contractor Galliford Try. AECOM responded to BAS's design brief by producing a compelling concept design for a sustainable research station that offered ease of delivery, construction, operation and decommissioning.

The successful delivery of Halley VI was a fantastic example of design, innovation, construction and procurement at its best, requiring an intimate collaborative process between client, design team, main contractor and supply chain. The design and construction included unique technology transfers from other industries, and a range of totally original inventions .... The design for Halley VI centered on the need for survivability, maintainability, and livability. It was conceived to be not only a high-functioning, economical science base, but also a well-crafted social space — a home away from home for the dozens of scientists stationed there for as long as 18 months at a time. The design team worked closely with BAS to achieve the project's goals and the needs of the people living there.

Attention to detail was accorded the highest priority. Daybreak simulation lights and color psychology were used to counter seasonal affective disorder, supporting residents during the long winters. The central pod is designed to provide a comfortable social living space that can flexibly accommodate as many as 60 people during the summer months. Large areas of high-performance glazing bring the outdoors inside, providing insulation and stunning views across the ice. Naturally scented timber veneers remind residents living in a landscape without trees of an altogether different natural environment" (Ayres, Arctic living, csengineermag).



III 1:5 PHYSICAL CHALLENGES

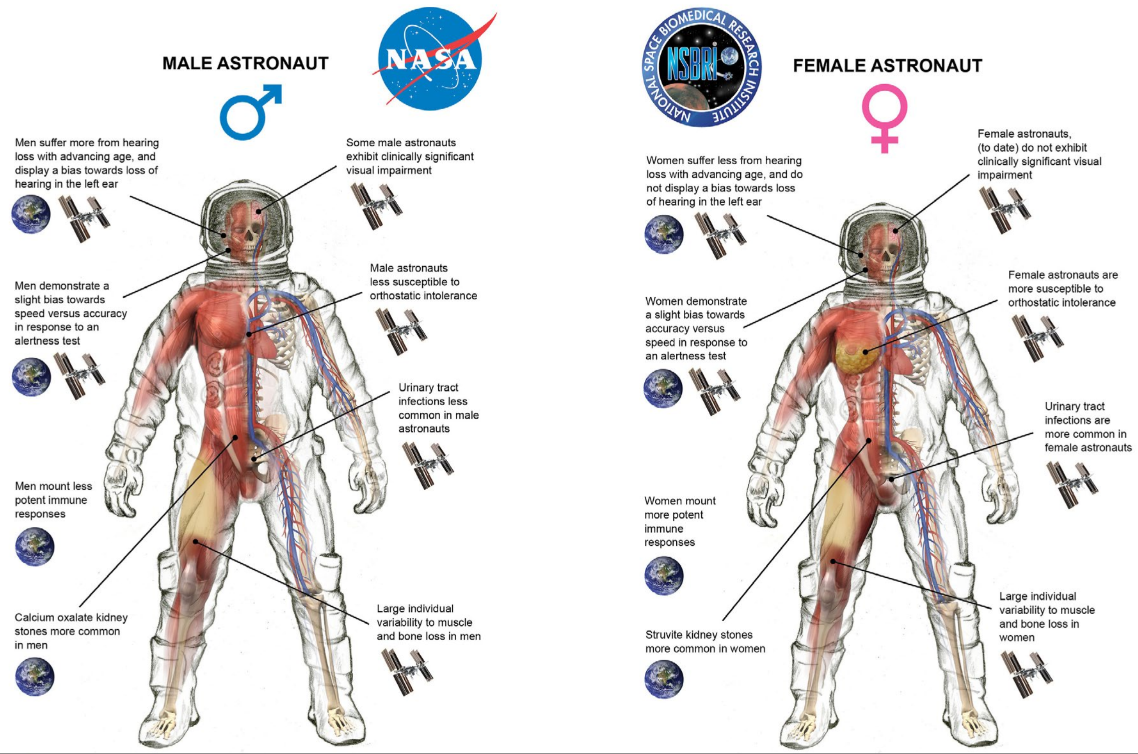
RADIATION

Radiation will present a significant challenge for human settlement on Mars. While living on the Red Planet, astronauts will be under a constant radiation exposure, putting their lives in danger. However, scientists at NASA have been working on different solutions to this problem. A science writer at NASA, Sarah Frazier wrote:

"The most dangerous aspect of traveling to Mars is space radiation. On the space station, astronauts receive over ten times the radiation than what's naturally occurring on Earth. Our planet's magnetic field and atmosphere protect us from harsh cosmic radiation, but without that, you are more exposed to the treacherous radiation. Above Earth's protective shielding, radiation exposure may increase your cancer risk. It can damage your central nervous system, with both acute effects and later consequences, manifesting itself as altered cognitive function, reduced motor function, and behavioral changes. Space radiation can also cause radiation sickness that results in nausea, vomiting, anorexia, and fatigue.

"**Radiation exposure may increase your cancer risk. It can damage your central nervous system, with both acute effects and later consequences, manifesting itself as altered cognitive function, reduced motor function, and behavioral changes.**

- NASA"



HEALTH EFFECT OBSERVED IN SPACE **HEALTH EFFECT OBSERVED ON EARTH**

You could develop degenerative tissue diseases such as cataracts, cardiac, and circulatory diseases. The food you eat and the medicine you take must be safe and retain their nutrient and pharmaceutical value, even while being bombarded with space radiation. A vehicle traveling to Mars and a habitat on Mars will need significant protective shielding, which is nonetheless futile against some types of space radiation.

The Key: The space station sits just within Earth's protective magnetic field, so while our astronauts are exposed to ten times higher the radiation than on Earth, it's still much less than the radiation a mission to Mars will encounter, and of a different type. Shielding, monitoring, and operational procedures control the radiation risks to acceptable levels to keep you safe. To learn what happens above low Earth orbit, NASA has extensively used ground research facilities to study how radiation affects biological systems, and more importantly, how to protect them. They are developing unique ways to monitor and measure how radiation affects you while living in space, and to identify biological countermeasures. Finally, methods to optimize shielding are being studied to help protect us on a journey to Mars" (NASA/Johnson Space center, Gravity – Who needs it, ecnmag).

> **“SELF-RELIANCE IS STILL THE KEY FOR FUTURE COLONIZATION OF MARS.”**

While NASA's ambitious experiments are making progress in developing sophisticated solutions to deflects radiation, self-reliance is still the key for future colonization of Mars. Future Martian colonists will need to learn to be independent of Earth and relay more on Martian recourses. The make-up of the Martian soil is similar to that of Earth, which potentially can be a great resource for building materials; solving many of the physical challenges we face today. This is another area where architects can add a valuable contribution to the Space Industry. On Earth, architects have been designing spaces for human inhabitation through creative use of materials for centuries. As we continue working on finding ways to relay on Martian resources, this rich understanding and knowledge in the use of materials can be very valuable. This is the reason why NASA has been reaching out to architects and architecture students. The architecture profession can provide the space industry with valuable design solutions to some of the physical challenges.

NASA 3-D PRINTED CHALLENGE

In 2015, as part of NASA's efforts, the Centennial Challenges program created a 3-D Printed Habitat Design Competition. The design competition challenged participants to design architectural concepts that can take advantage of Martian resources using 3-D printing technology. Participants from the architecture profession were able to come up with creative solutions, "The creativity and depth of the designs we've seen have impressed us," said Centennial Challenges Program Manger Monsi Roman. "These teams were not only imaginative and artistic with their entries, but they also really took into account the life-dependent functionality our future space explorers will need in an off-Earth habitat" (Ramsey, NASA Awards 3-D Printed Habitat Challenge, NASA). The interest NASA placed in these design competitions is a clear indication of the value architects can have on the space industry.

> **These teams were not only imaginative and artistic with their entries, but they also really took into account the life-dependent functionality our future space explorers will need in an off-Earth habitat.**
>
> -Monsi Roman/ NASA

DESIGN COMPETITION - TEAM N3ST

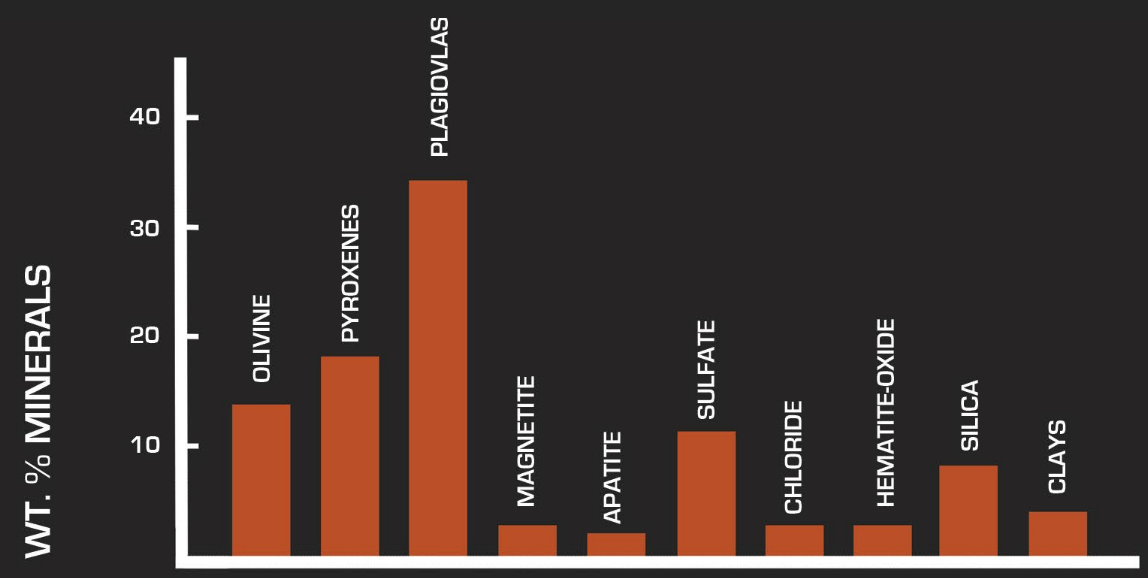
One of the participating teams was N3ST (Nested 3D-printed settlement Technology), delivered a creative design solution that took advantage of Martian resources using 3-D printing technology:
"N3ST is a safe-to-fail design based on the principles of redundancy, simplicity, and incrementalism, which aims 1) to provide atmospheric stabilization, to allow robotic-building in safe conditions, minimizing error and robot failure; 2) to create a life-supporting milieu, granting the physiological conditions necessary for human life; and 3) to generate functional, comfortable infrastructure, understood as design solutions oriented to efficiently support anthropogenic use of the space. These goals are achieved by way of three functional layers: The Exo-layer provides a primary protection to the settlement, that is, to quickly stabilize atmospheric conditions for further development of tasks that require greater control. The Meso-layer is a hermetic volume which provides an atmosphere with the necessary physiological conditions for sustaining the human life, controlled by the ECLSS. Finally, the Endo-layer creates all the necessary for the development of the activities performed by the crew members, like furniture and resources supply networks" (NASA 3D-Printed Habitat Challenge, 3dpchallenge).

III 1:6 MATERIALS

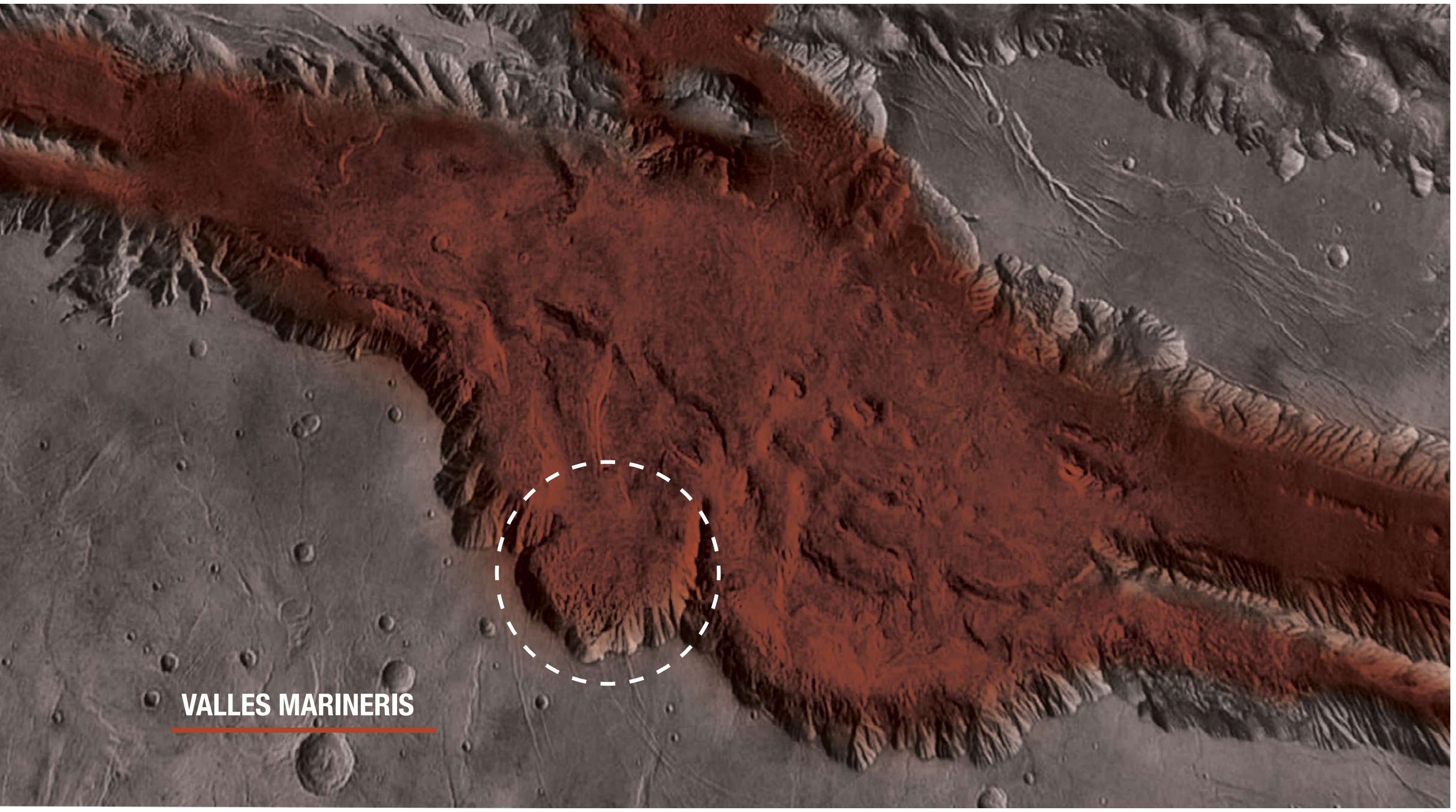
MARTIAN CONCRETE

In our efforts to colonize Mars, 3D- printing technology has limitless potential. However, this potential can not be actualized if this technology didn't implement the raw resources on Mars. The challenge humanity is facing as we move forward with colonizing Mars is the need to bring materials from Earth, which will be incredibly expensive. This need inspired a group of researchers at Northwestern University to create a new building material from the Martian soil: sulfur concrete.

"The challenge humanity is facing as we move forward with colonizing Mars is the need to bring materials from Earth."



SITE MINERAL STUDY

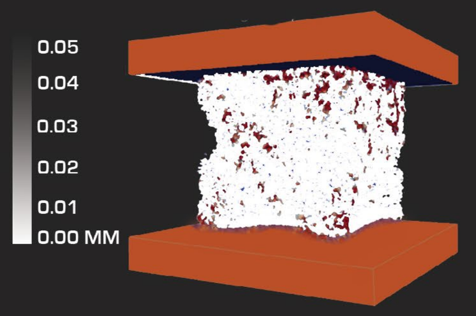


"Most Earth concrete, the primary building block of modern construction, requires water mixed with cement and gravel. Sulfur, which is widely available on Mars, can take the place of water and bind the concrete together. Scientists tested out different mixes of simulated Martian soil with sulfur and found the optimal concrete recipe for a sturdy Red Planet abode.

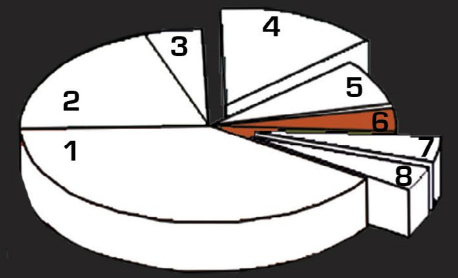
Sulfur concrete made with Martian soil came out twice as strong as its Earthly counterpart, says corresponding author Gianluca Cusatis, an associate professor at Northwestern's Department of Civil and Environmental Engineering. He thinks this is because the sulfur bonds chemically with the minerals found in Martian soil, whereas on Earth the sulfur only serves as glue for the gravel. Furthermore, since gravity on Mars is one-third what it is on Earth, the strength is effectively tripled.

This material, then, has the strength needed to construct a shelter. But it also solidifies in an hour or less. Even fast-setting concrete takes 24 to 48 hours, Cusatis says, and regular concrete needs up to 28 days to set. That makes sulfur concrete much more attractive for 3-D printing, which is likely to play a role in construction on other planets. Probably most significant, though, is the farm-to-table aspect" (Spector, How to build…using only materials on mars, citylab).

CONCRETE TESTING



MARTIAN SOIL MAKEUP



1 Oxygen
2 Silicon
3 Calcium
4 Iron
5 Potassium
6 Cesium
7 Sulfur
8 Magnesium

MARTIAN CONCRETE STRENGTHS

- 2 TIMES STRONGER THEN EARTH'S
- SHAPE FLEXIBILITY
- FORMED WITHOUT USING WATER

“SULFUR CONCRETE MADE WITH MARTIAN SOIL CAME OUT TWICE AS STRONG AS ITS EARTHLY COUNTERPART.

- Gianluca Cusatis”

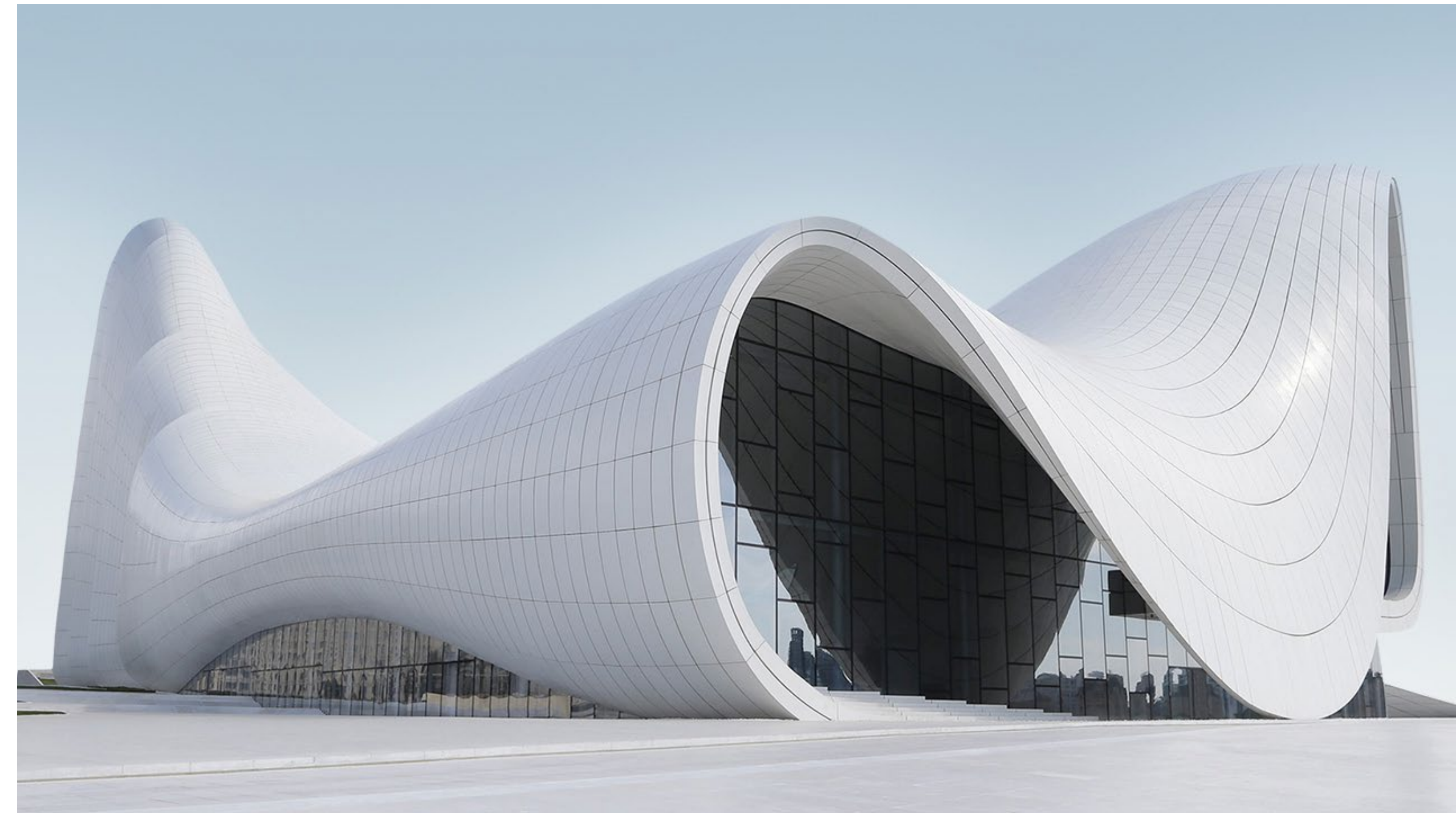
While we’re a long way from developing a Martian Concrete by taking advantages of the Martian soil using 3-D Printing technology, this can have a significant influence on the architecture profession. We already have architects, such as Zaha Hadid challenging and pushing the traditional use of Earth’s concrete, creating a new type of architectural spaces using conventional concrete. By the time architects like Zaha Hadid break ground on the Red Planet, Martian architecture will be out of this world.

“SULFUR CONCRETE MUCH MORE ATTRACTIVE FOR 3-D PRINTING, WHICH IS LIKELY TO PLAY A ROLE IN CONSTRUCTION ON OTHER PLANETS.

- Gianluca Cusatis”

CASE STUDY
HEYDAR ALIYEV CENTRE

ARCHITECT: ZAHA HADID
LOCATION: AZERBAIJAN
MATERIAL: GLASS FIBER CONCRETE
YEAR: 2013



PLASTIC BOTTLES

FURNITURE

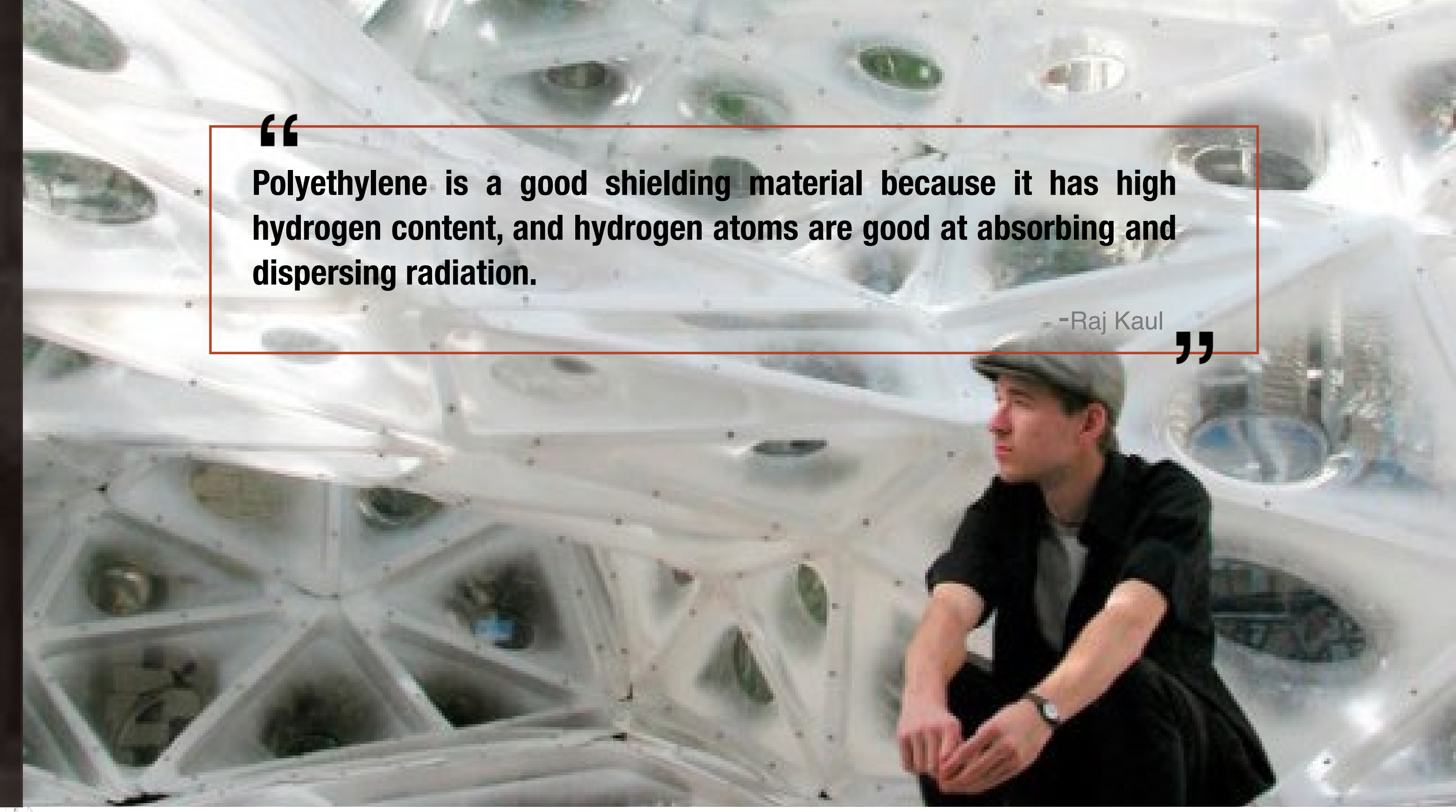
SPACE ROCKET COMPONENTS

ORGANIC ART INSTALLATION

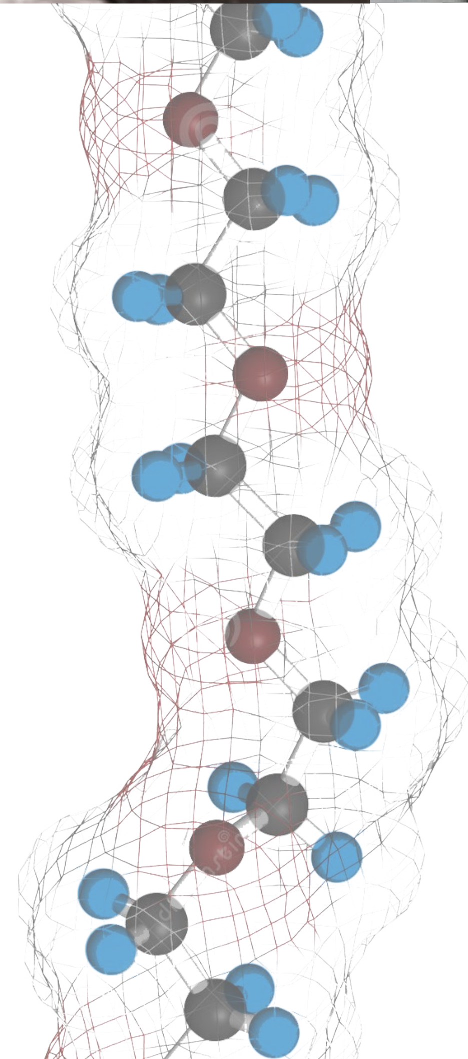
RXF1 (POLYETHYLENE)

NASA has developed another groundbreaking type of building materials that has a great potential in space. Polyethylene, the same materials found in water bottles and plastic bags, has the potential to shield astronauts from harmful space radiation. Polyethylene has a high content of hydrogen, which is excellent at absorbing radiation. Scientist at NASA call the new material RXF1. An editor at NASA, Jim Wilson, interviewed members of the Radiation Shielding Program at NASA, and wrote:

"The team is examining new shielding materials that not only block and/or fragment more radiation than aluminum -- the material currently used to build most spacecraft structures -- but also are lighter than aluminum. Spacecraft designers have to be able to shape shielding materials to make various parts of the spacecraft. The material must protect the crew from radiation, and it must also deflect dangerous micrometeoroids. The shielding must be durable and long lasting -- able to stand up to the harsh space environment.



> **Polyethylene is a good shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation.**
>
> -Raj Kaul



Polyethylene is a good shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation. In fact, researchers have been studying the use of polyethylene as a shielding material for some time. One of several novel material developments that the team is testing is reinforced polyethylene. Raj Kaul, a scientist in the Marshall Center's Engineering Directorate, previously has worked with this material on protective armor for helicopters.

"Since it is a ballistic shield, it also deflects micrometeorites," Kaul says. "Since it's a fabric, it can be draped around molds and shaped into specific spacecraft components."

Kaul makes bricks of the material by cutting the fabric and layering 200 to 300 pieces in a brick-shaped mold in his laboratory at the Marshall center. He then uses a vacuum pump to remove air and prevent bubbles in the material, which would reduce its strength.

The material is "cooked" in a special oven called an autoclave, which heats the material slowly to 200 degrees Fahrenheit while putting it under pressure of 100 pounds per square inch using nitrogen gas. The combination of heat and pressure causes the chemical reaction that bonds the layers together to form a brick weighing about half as much as a similar piece of aluminum" (Wilson, Shields to protect future space crews, NASA).

> **Since it's a fabric, it can be draped around molds and shaped into specific spacecraft components.**
>
> -Raj Kaul

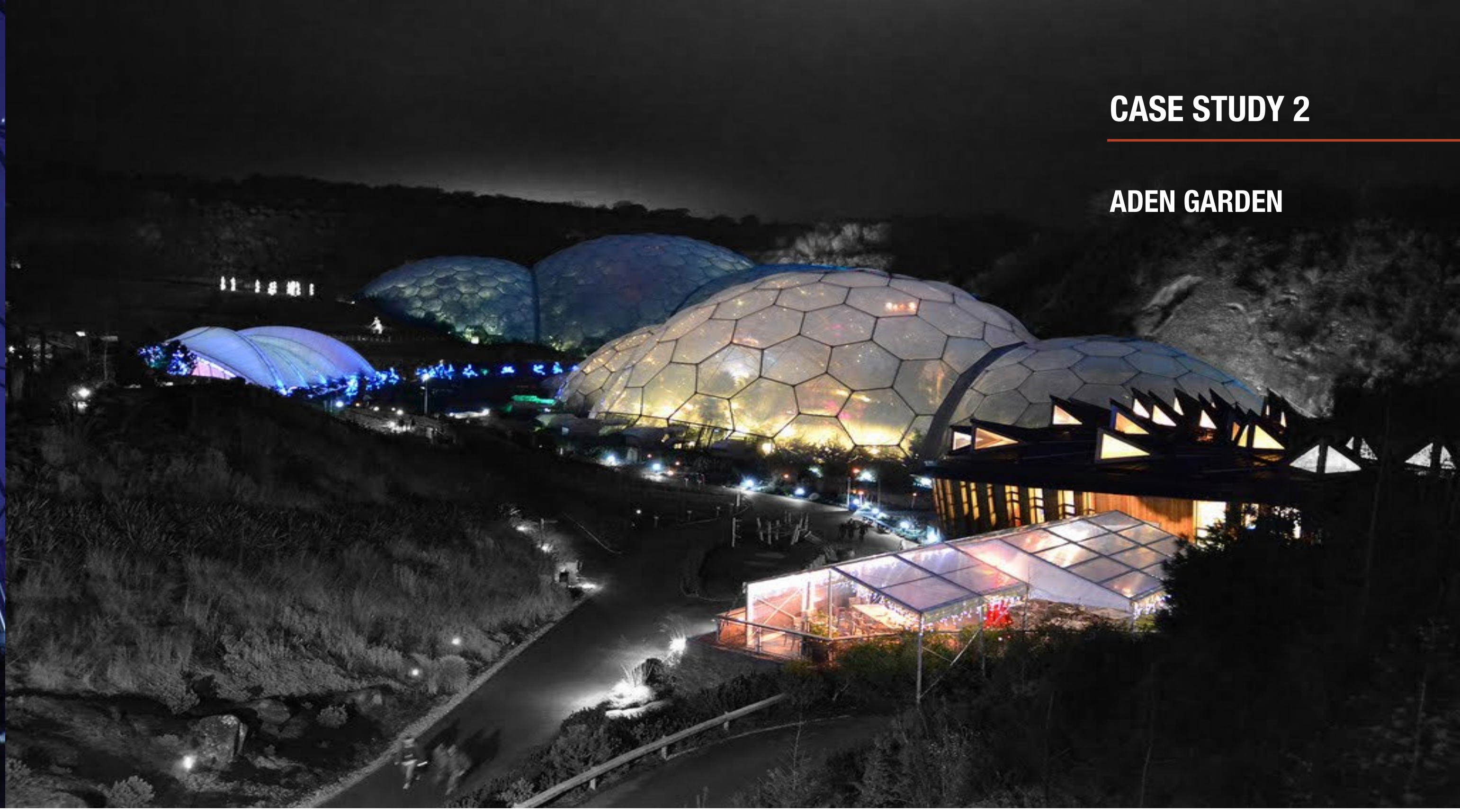
ADOPTIVE USE FOR RXF1 (POLYETHYLENE)

This material can be a useful tool for not only deflecting radiation in space but also for a flexible and lightweight building material. Although self-reliance is a key for a future colony on Mars, human beings still need to be living in spaces that accommodate for their physical and psychological daily needs. The flexibility and strength of this material can be adopted to design modular structure that can be constructed on Earth and transported to Mars. Architects and experts from different disciplines can work to develop an aesthetically pleasing interior layer that accommodates for the daily needs of astronauts.

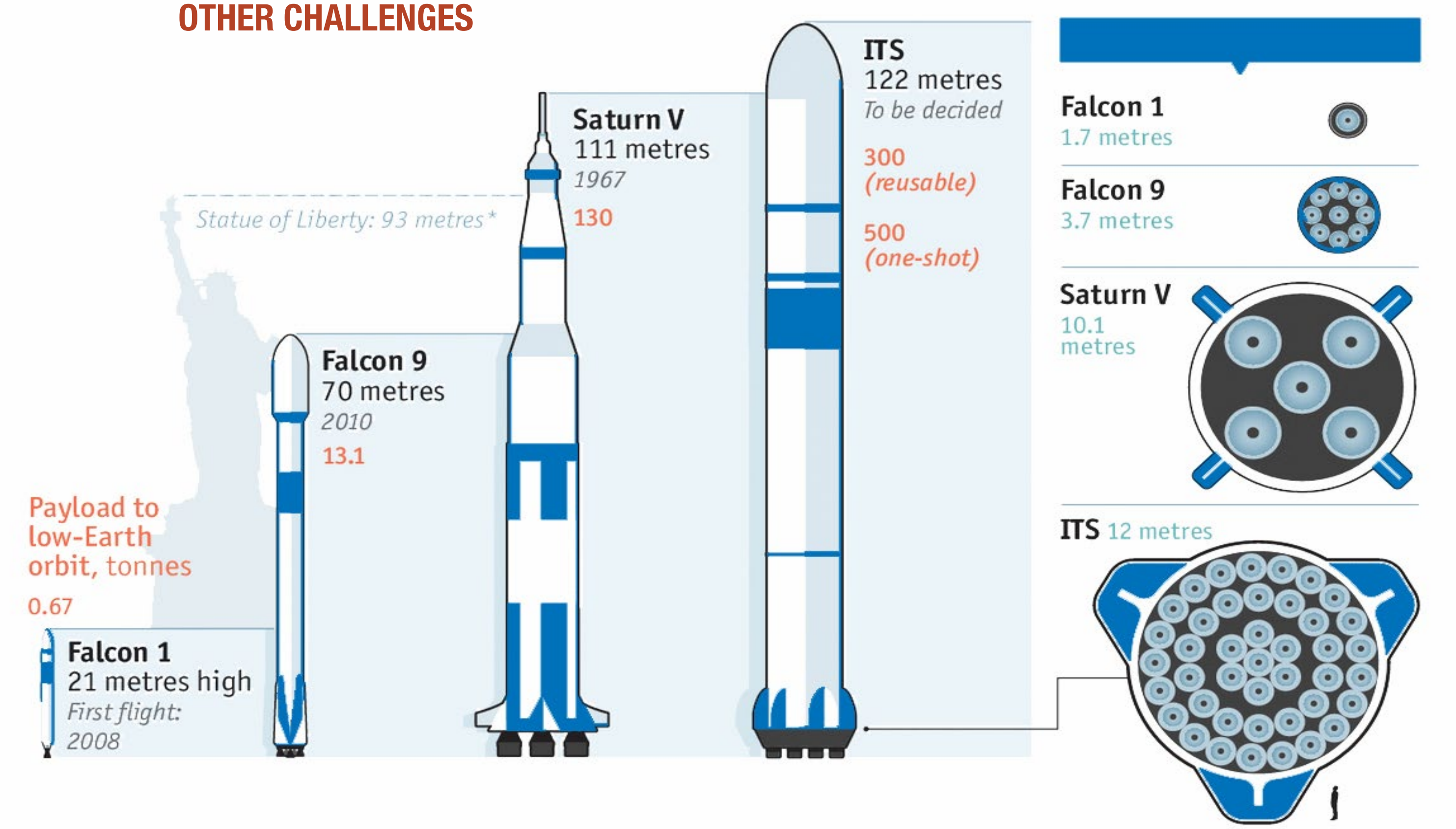
As it's seen in the next two case studies, architects have been working with a similar version of the same material for years, creating environments that shape how people feel and behave.

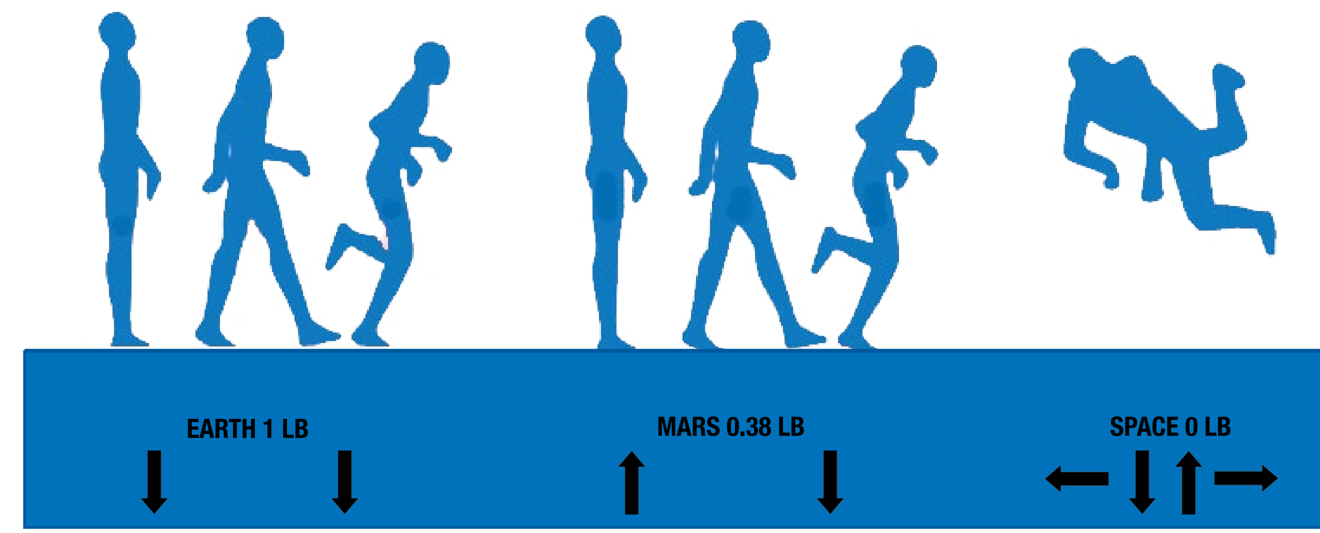
CASE STUDY 2

ADEN GARDEN



OTHER CHALLENGES



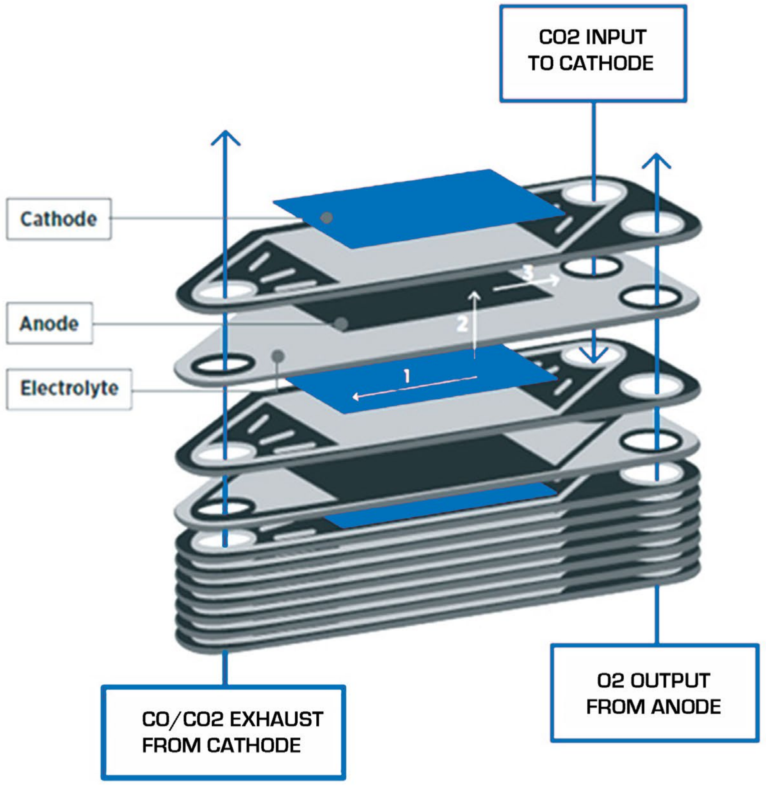


PAYLOAD LIMITATION

The current rocket engine technology is capable of lifting 135 tons of payload to escape earth's gravity. But SpaceX is developing a new type of engine called "Raptor", which is capable of lifting 550 tons of payload. SpaceX is planning on using this technology in its mission to Mars.

EFFECTS OF GRAVITY ON MARS

The gravity of Mars is 38% that of Earth, which potentially can help with the landing of a spaceship. However, human bodies are not adopted to low level of gravity, and in the long run this can change the muscle and bone structure. On average, humans lose about 1-2% of bone mass every 3 months on the surface of Mars (Marwaha, How will living on Mars affect our human body, spacesaftymagazine).



1 — CO_2 flow
2 — O^{2-} passed through electrode
3 — O_2 flow

AIR & FUEL PRODUCTION ON MARS

Air and Fuel production is one of the major issues that needs to be solved before human-kind is able to colonize Mars. NASA is preparing to test Moxie on its exploration mission to Mars in 2020. MOXIE will demonstrate how future explorers produce oxygen from the Martian atmosphere for propellant and for breathing. MOXIE collects carbon dioxide from the Martian atmosphere, compresses and stores it, and then electrochemically splits it into breathable air and water to drink. This technology will enable human exploration and self-sufficient future colony (Mars oxygen ISRU experiment- MOXIE, mars.nasa).

GROWING FOOD ON MARS

NASA scientist are questioning whether Martian grown food would be safe to eat. The Martian soil is full with metal, which can be toxic. In a Martian soil simulation, scientist found that the food had not absorbed the toxic metal found in the Martian soil (Nosowitz, Scientists grow vegetables on Martian soil, modernfarmer).

APPLYING RESEARCH TO CONCEPTUAL ARCHITECTURAL DESIGN

SOL IV

IV 1:1 DESIGN OBJECTIVE

The objective is to incorporate the research to develop a conceptual architectural design for a permanently manned, self-sustaining Martian Research Center. The Martian Research Center will take place in the next 50 to 100 years, and will accommodate 20 scientists and astronauts. The goal is to incorporate the major programs required for long-term habitation in the isolation of the Martian environment into a thriving ecosystem. These functions include living, sleeping, working, medical and communication facilities that provide the physical and psychological needs of its inhabitants. The design goal is to focus on the interior layout of the building while investigating the proper structure, materials, and construction techniques. The general concept is to create a comfortable, safe living environment for the twenty members of the team.

MISSION GOALS

Self- Sufecient Colony
Charachterize Martian Geology
Understand Martian Climate
Search For Life

IV 1:2 MISSION CREW

Astrobiologists _ the study of the origin, evolution, distribution, and future of life in the universe: extraterrestrial life and life on Earth.

Medical Personal_ a person who is skilled in the science of medicine: a person who is trained to treat sick and injured people.

Commander_ a person in authority with other set of skills.

Pedology _ the study of soils in their natural environment. It is one of two main branches of soil science.

Meteorologist- researches the atmosphere, forecasts weather and studies the effect climate has on the planet and its people.

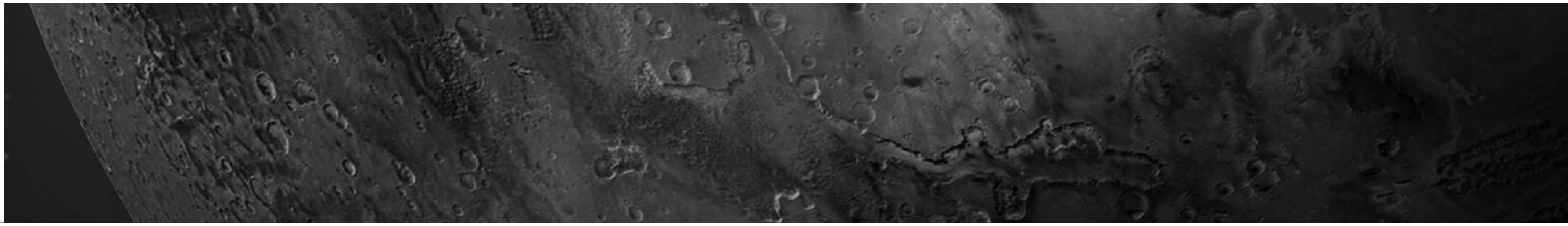
Biologist_ a scientist who studies life, specifically organisms and their relationship to their environment.

Botanist_ a scientist who specializes in the science of plant life. Psychologist is someone who studies the mind and behavior.

Computer Scientist_ a scientist who has acquired the knowledge of computer science and information.

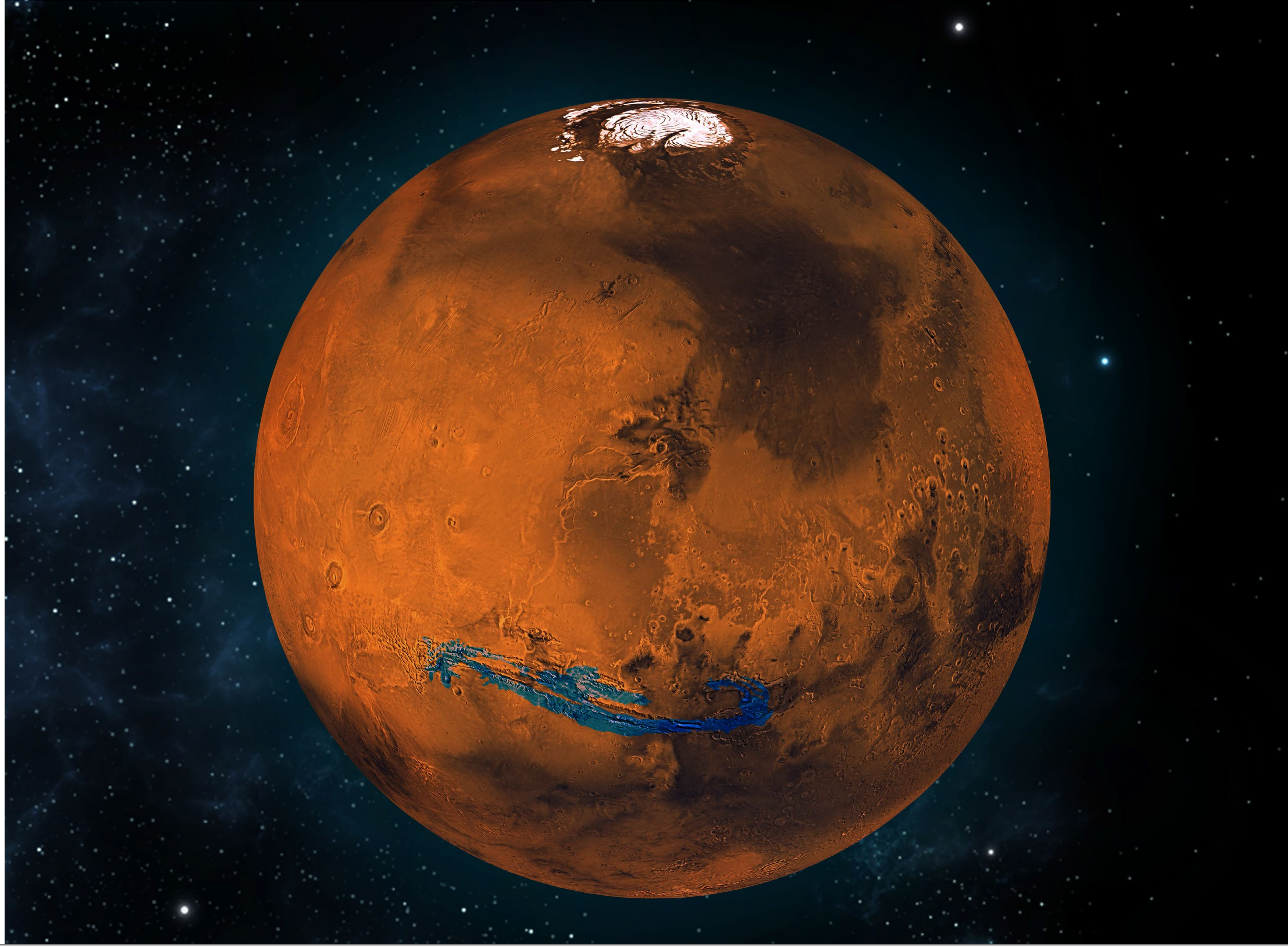
Engineer_ repairs machines or electrical equipment.

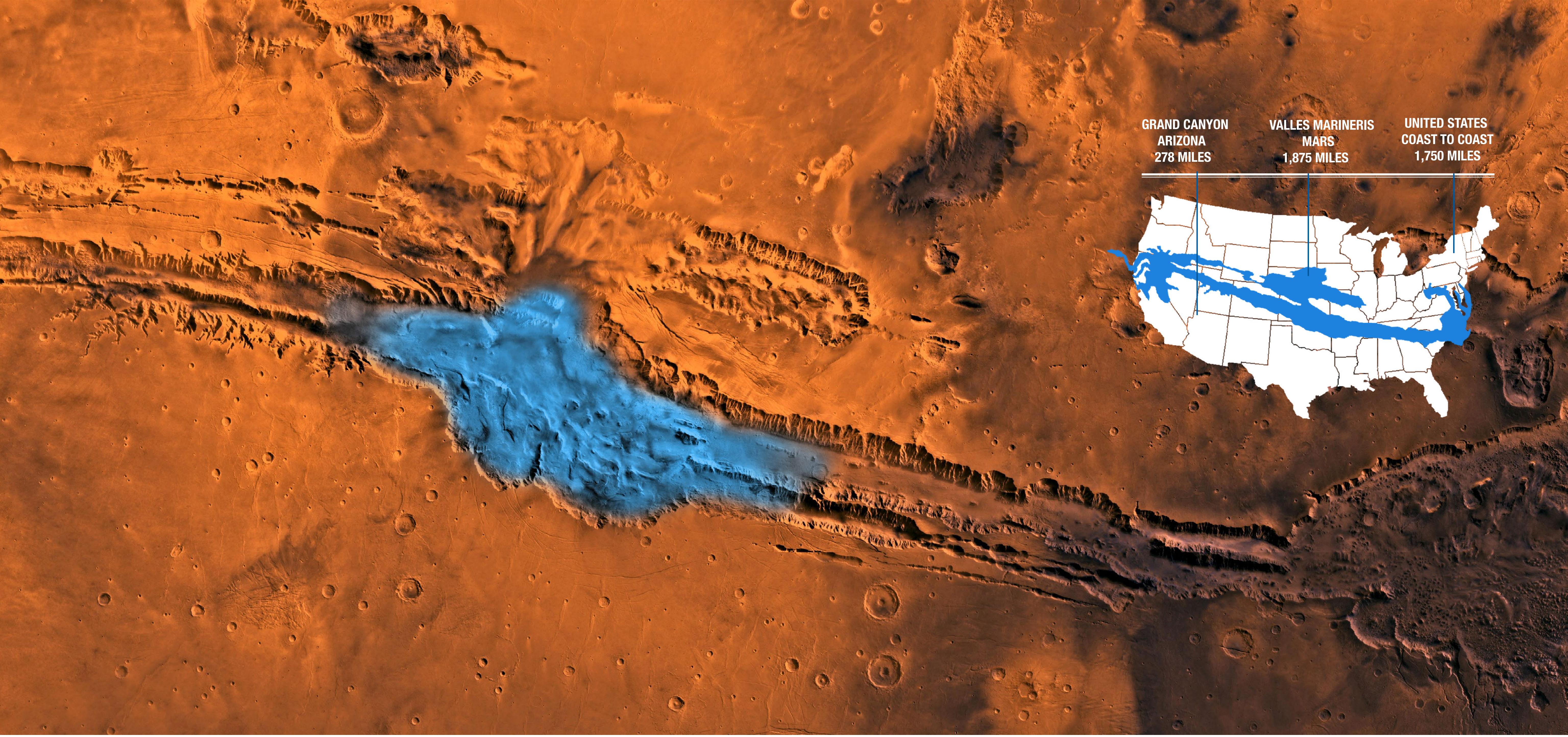
IV 1:3 SITE LOCATION



MELAS CHASMA

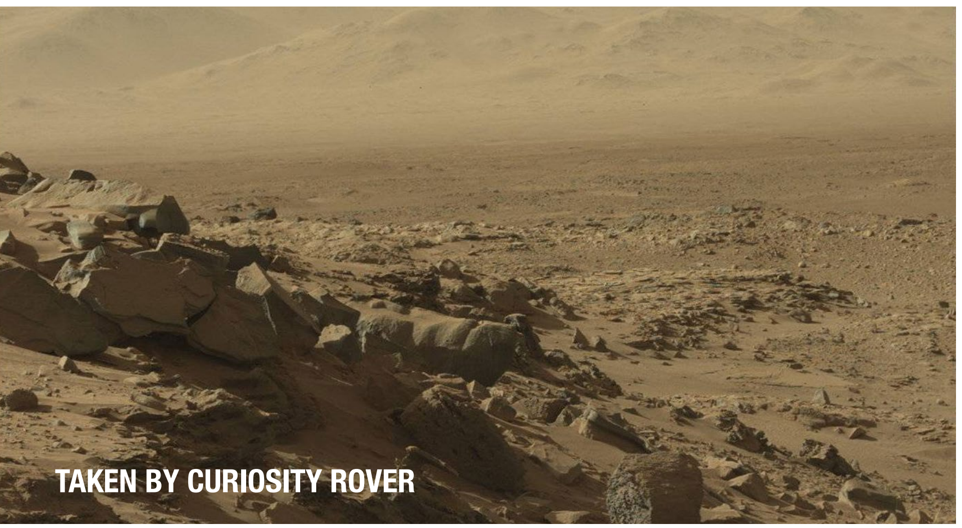
Mars has the longest and deepest canyon system anywhere in the solar system. Valles Marineris extends for nearly 2,500 miles, making it about nine times longer than earth's Grand Canyon. Within Valles Marineris a smaller canyon called "Melas Chasma" which is the widest segment of it. It is the deepest part of the Valles Marineris system at eleven kilometers (Atkinson, Melas Chasma, universtoday).





DEPTH OF GRAND CANYON & VALLES MARINERIS


TAKEN BY CURIOSITY ROVER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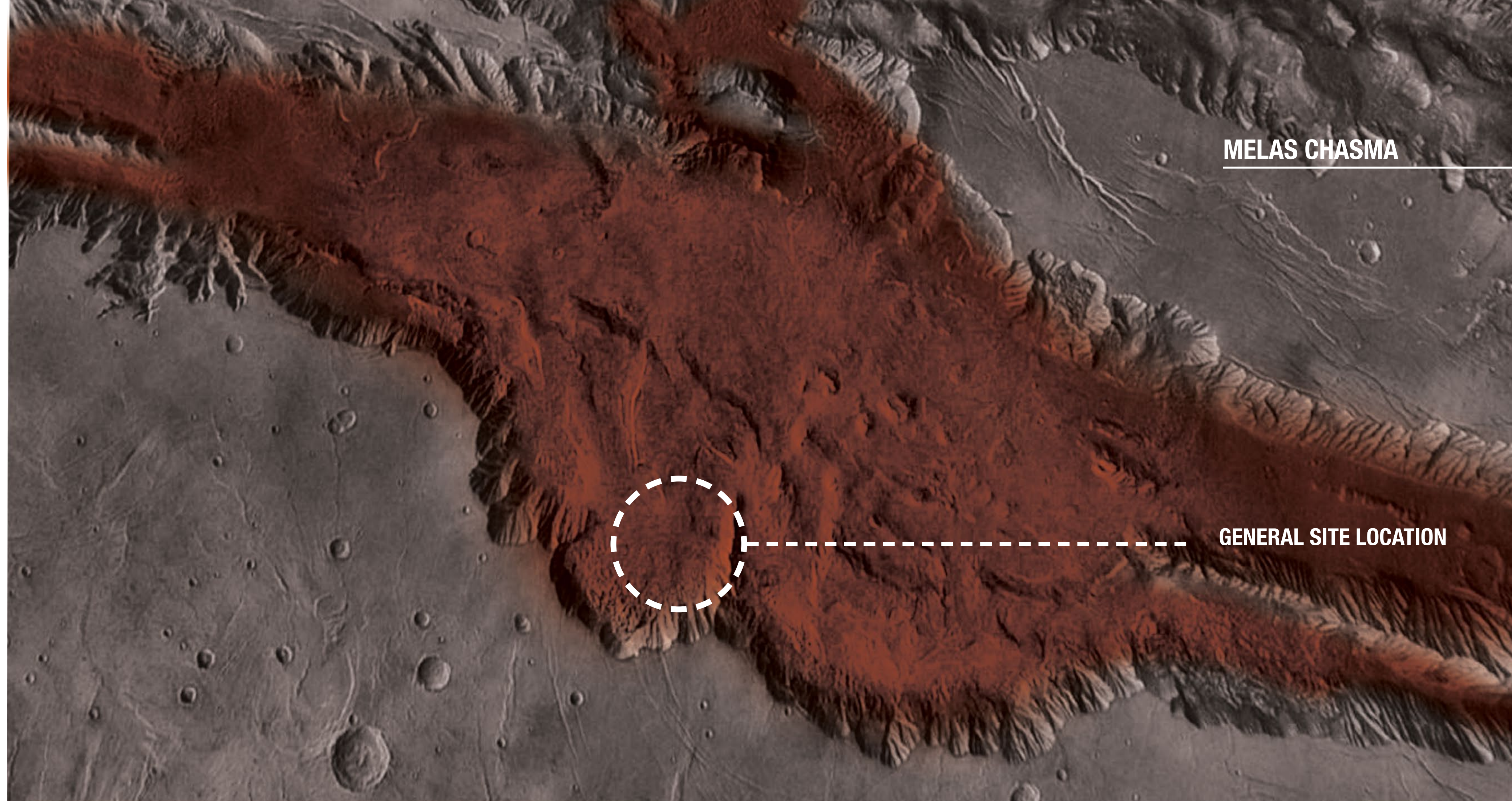
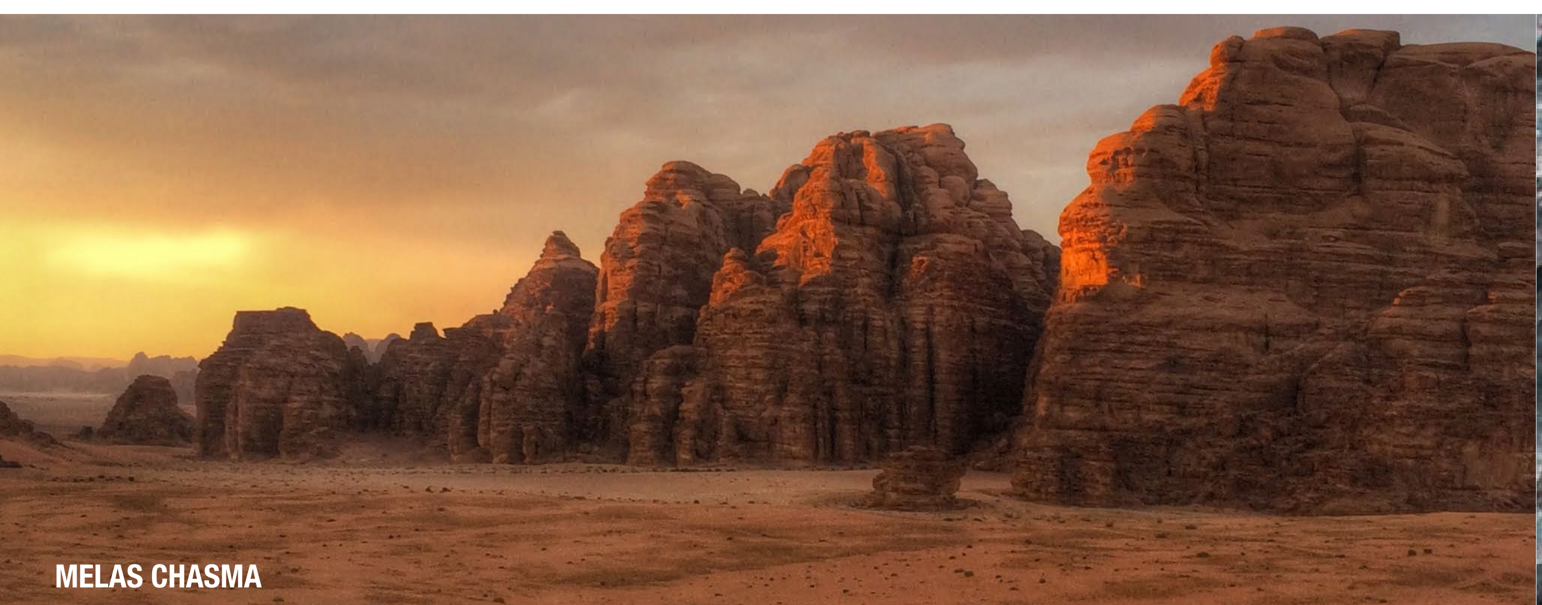
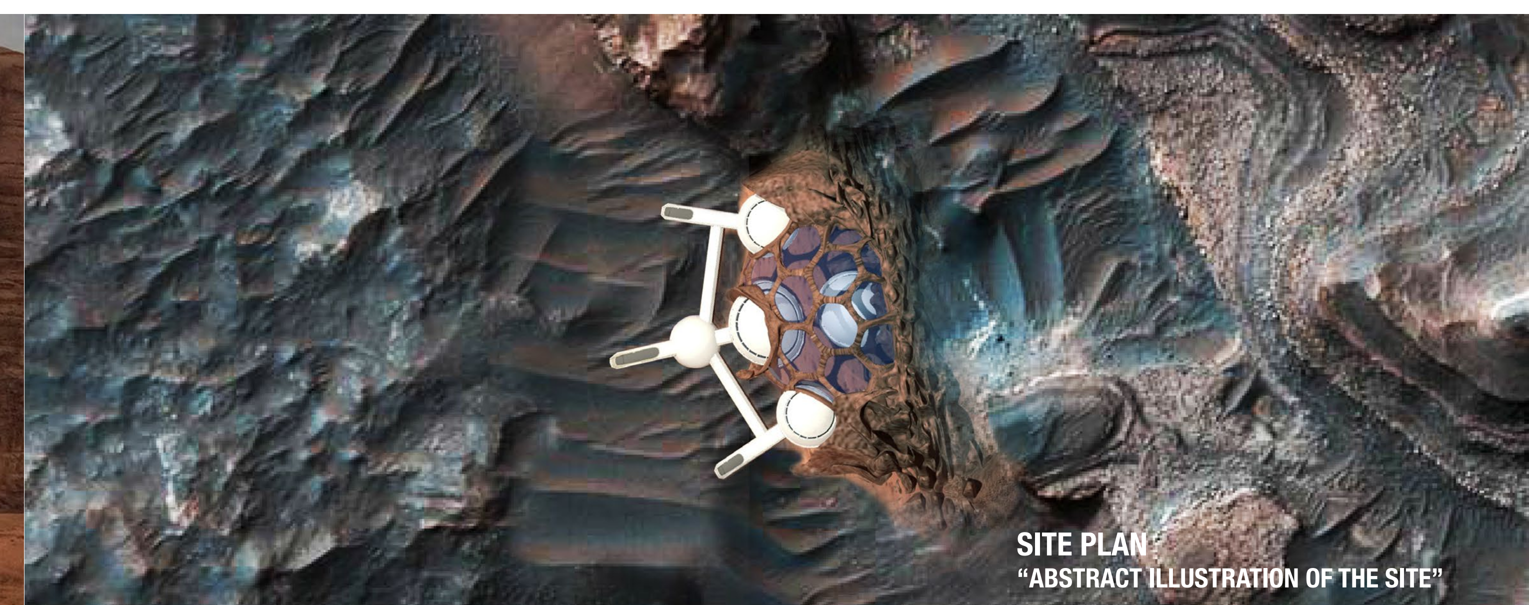


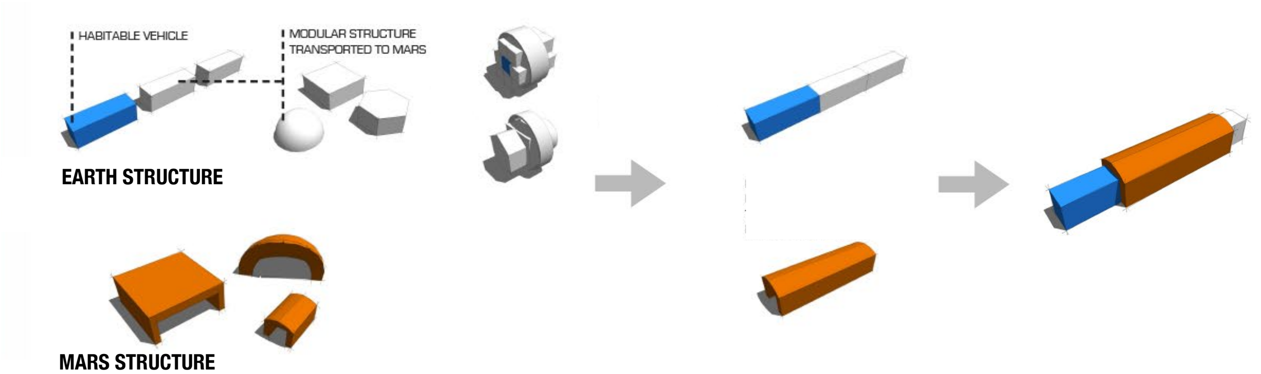

MELAS CHASMA


SITE PLAN
“ABSTRACT ILLUSTRATION OF THE SITE”

IV 1:4 DESIGN PROCESS

MISSION TIMELINE DIAGRAM

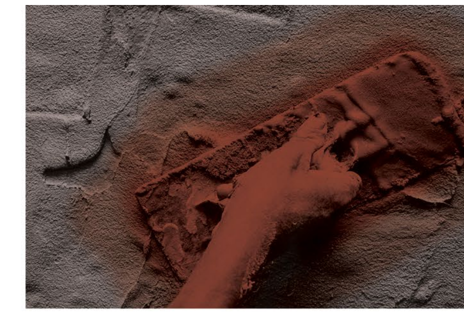
MODULAR STRUCTURE DIAGRAM



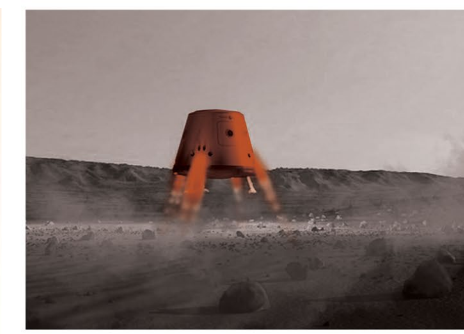
Earth Modular Structure + Martian Concrete Structure

Modular Structure Transported under the Martian Concrete Structure.

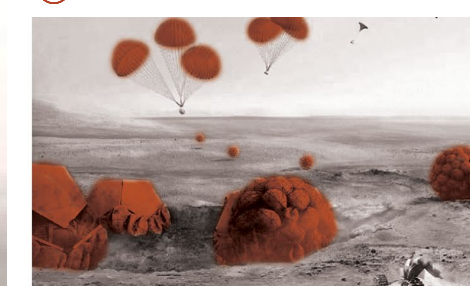
① EQUIPMENT TRENSPORT



② MARTIAN CONCRETE

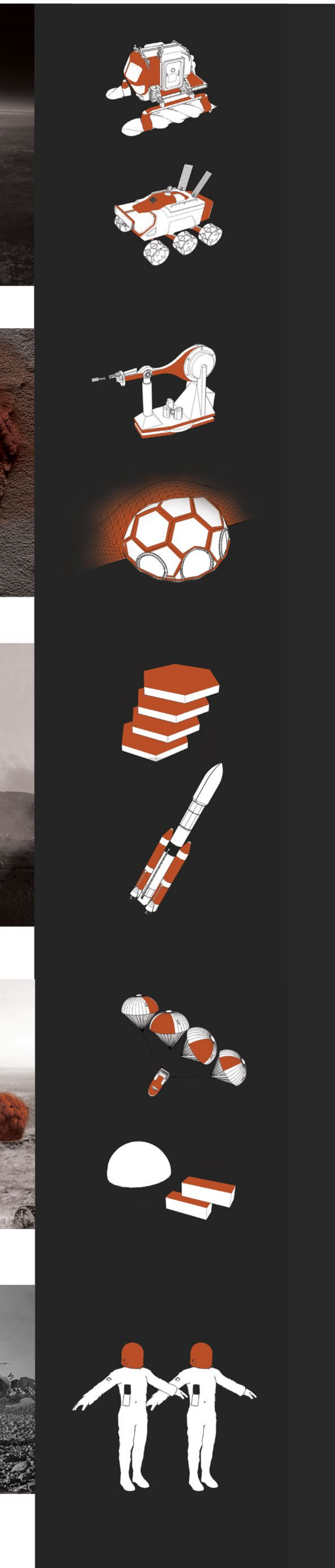


③ PANELS TRENSPORT



④ MODULAR TRENSPORT

⑤ ARRIVAL OF ASTRONAUTS



DESIGN PROCESS DIAGRAM

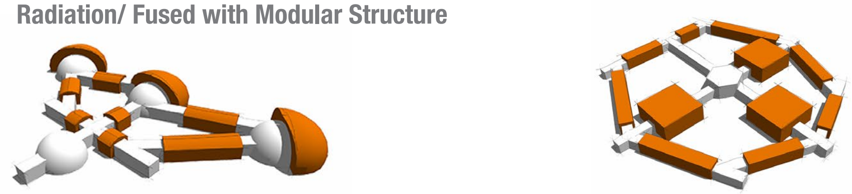
Program

Circulation

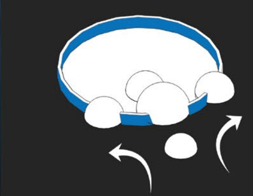
Fused Environments

Radiation/ Martian Structure

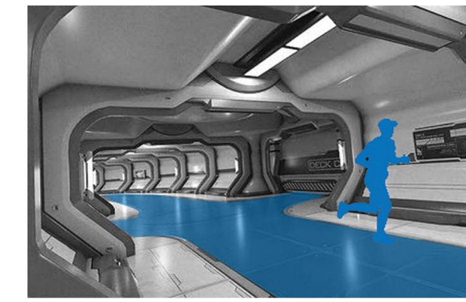
Radiation/ Fused with Modular Structure

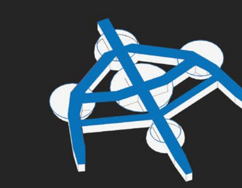


Mobility

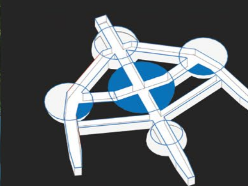


1 MARTIAN DUST STORM



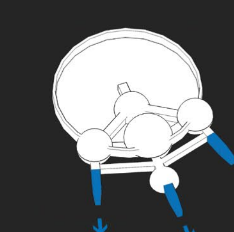


2 CIRCUALTION



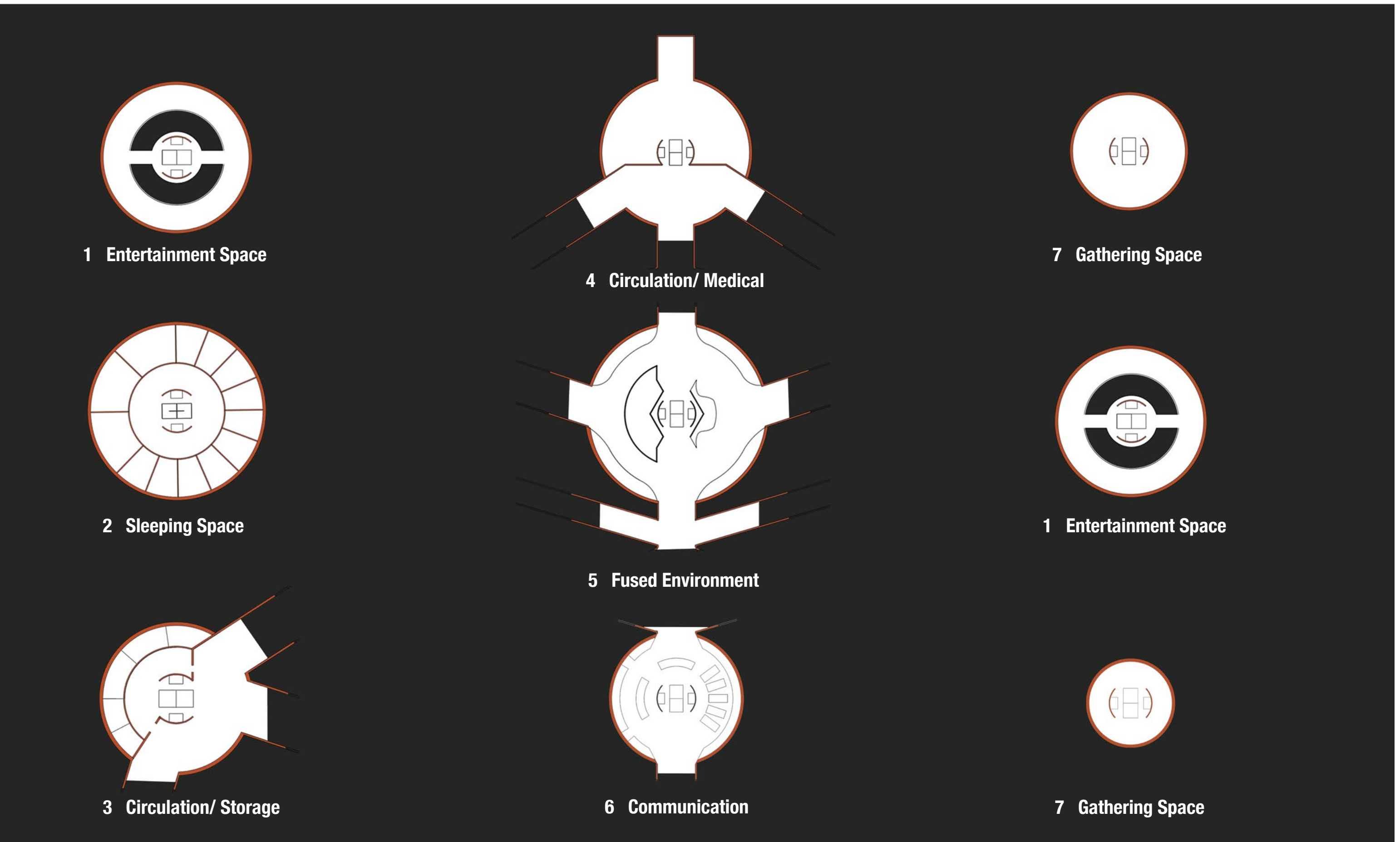
3 FUSED ENVIRONMENTS

4 RADIATION

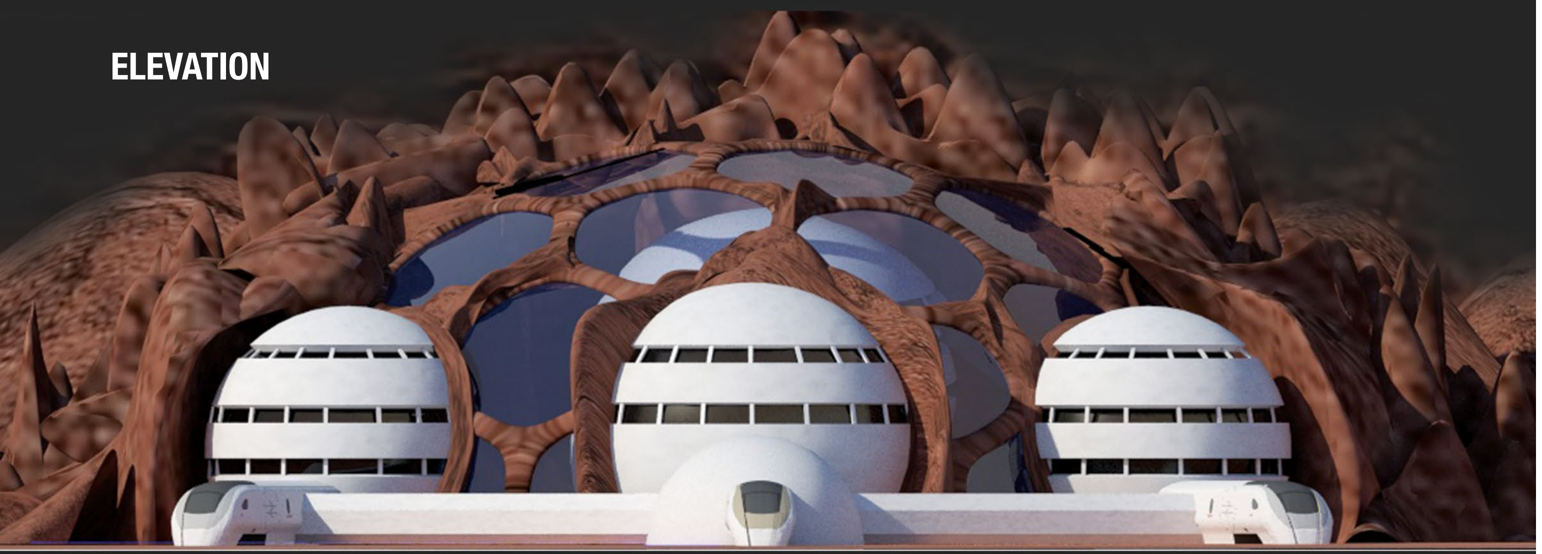


5 MOBILITY

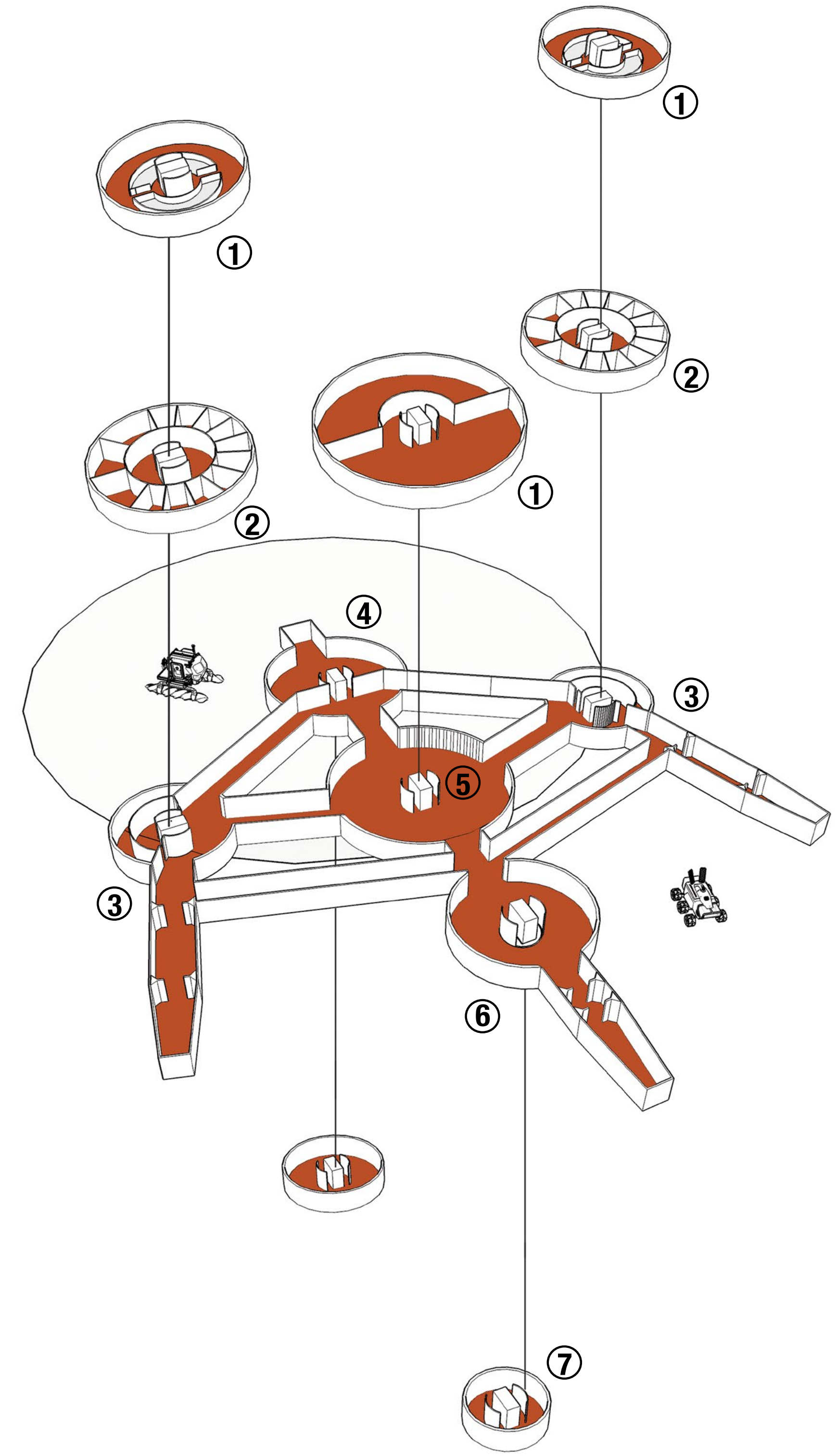
FLOOR PLANS



ELEVATION

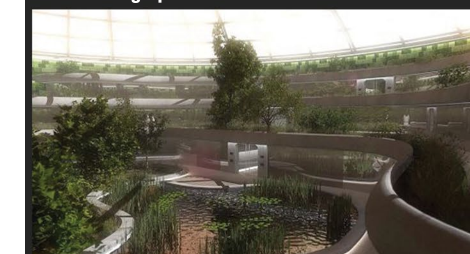


PROGRAM DIAGRAM




Entertainment Space


Gathering Space

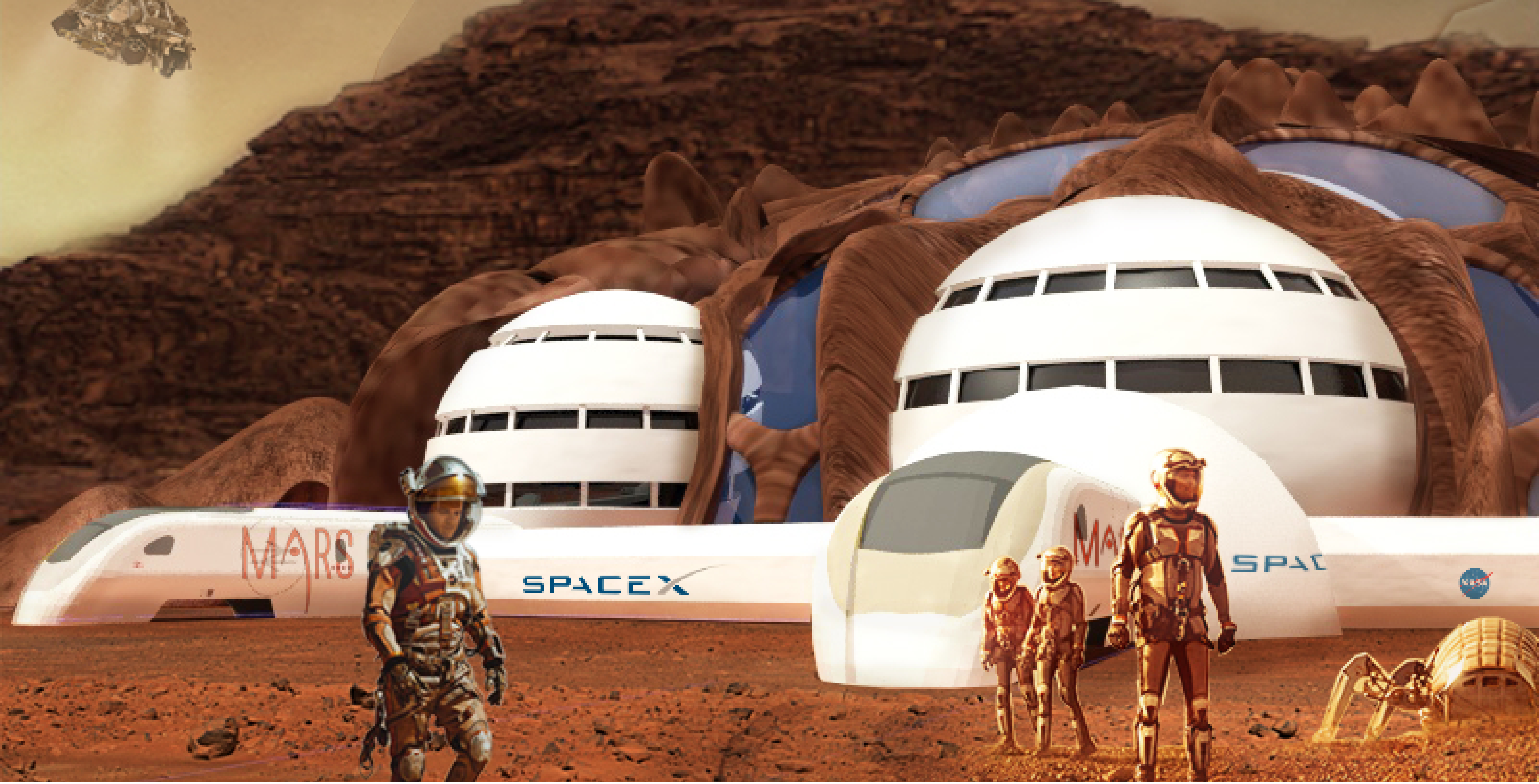

Opportunity Space

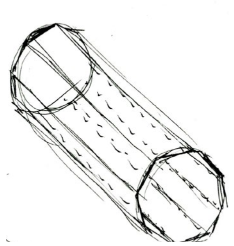

Fused Environment

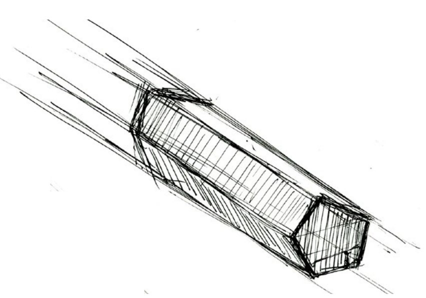

Medical

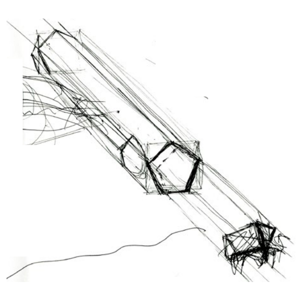

Mobility

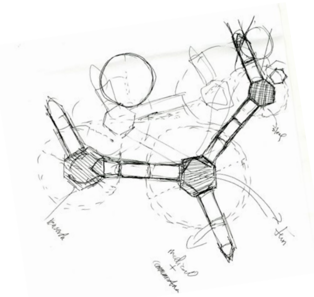

Circulation

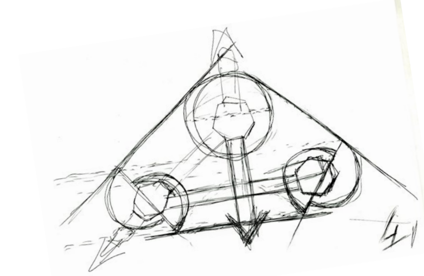

MARS
SPACEX



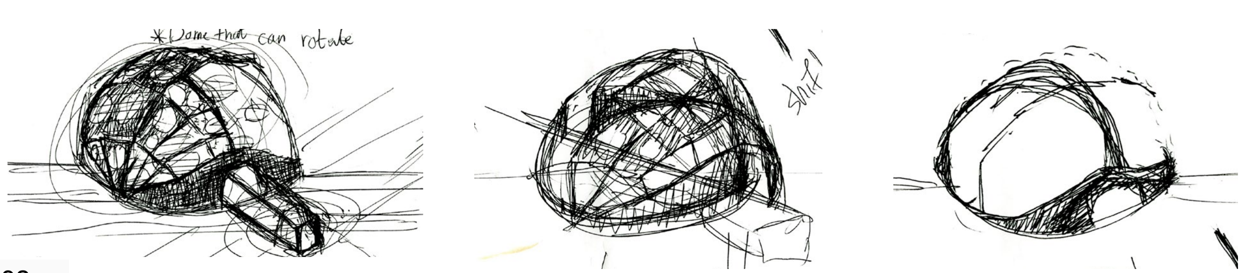


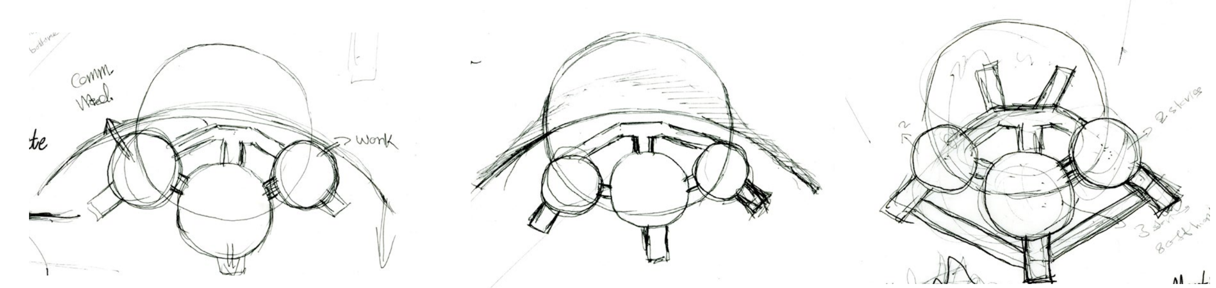




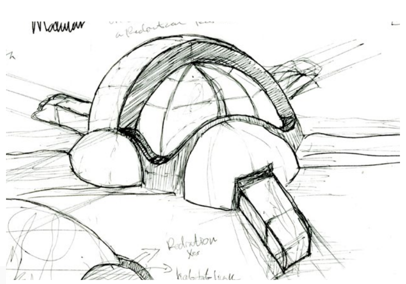


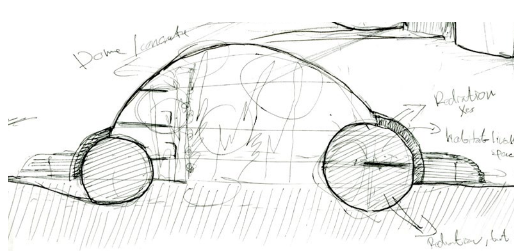

Option
Different Domes
with different environments
dome

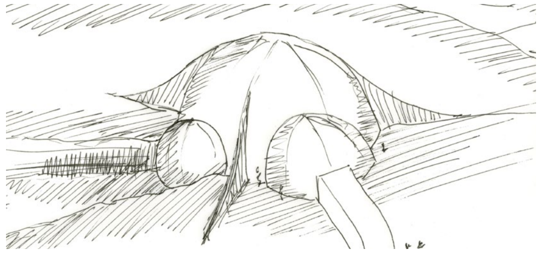

*Dome that can rotate

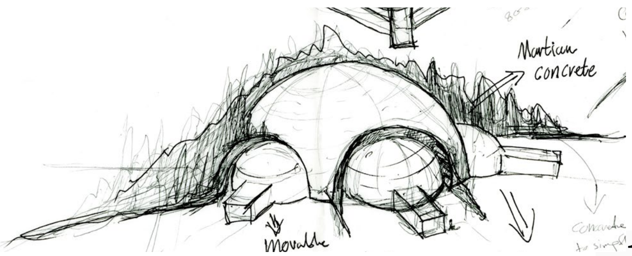

work


SPACEX
SPACEX
NASA
MARS








Martian concrete

SOLV

CONCLUSION

One of the most challenging and exciting problems we face today is space exploration and how to extend human consciousness beyond earth. The Outer Space Industry is dominated by engineers, astrophysicists and scientists, however, that won't be for too long. The industry is going through a critical shift from "how" to "when" will we be colonizing and exploring Mars. As designers, problem solvers and architects, we have the responsibility to look beyond what is in front of us. We need to use our expertise, imagination, and creativity to collaborate with other industries to solve the significant issues. It's an opportunity for us to define and assert our role in a major industry that can influence the world's economy and define our place in the universe. Being part of this industry is not only an exciting opportunity for architects to design a new world, but also an obligation.

This thesis is showing one of the infinite potentials an architect can contribute to the Outer Space Industry. Whether it's on earth or beyond, architects design environments that influence how people feel and think, architects have the power to shape how people interact with each other on a daily basis. The psychological challenges on Mars are as complicated and important as the physical; this is an opportunity for architects to define their role in the industry. While engineers and scientists can design functional structures to keep the astronauts' bodies protected from the harsh Martian environment, those confined spaces could make one feel isolated — pushing their mental abilities beyond its limits. This is where the expertise and creativity of an architect would be a very valuable asset in the space industry.

Architects design environments that influence not only the physical well-being but also the psychological well-being of people. The value of architects lies within their expertise in shaping environments through the use of materials, color, texture and a good spatial understanding that can influence the physical and psychological well-being of people in confined spaces.

This thesis has been one of the most challenging things I've ever experienced, physically and intellectually. It has been an incredibly rewarding and inspiring process. I hope I've evoked your curiosity in space exploration and the colonization of Mars…. and always remember, "Somewhere, something incredible is waiting to known".

BIBLIOGRAPHY

INFORMATION

Zubrin, Robert, and Richard Wagner. “Preface to the Revised Edition.” Preface. The Case for Mars: The Plan to Settle the Red Planet and Why We Must. New York: Free, 2011. Xi-Xii. Print.

Zubrin, Robert, and Richard Wagner. The Case for Mars: The Plan to Settle the Red Planet and Why We Must. New York: Free, 2011. Print.

“Mesopotamian Astronomy - Babylonian and Persian History.” Explorable - Think Outside The Box - Research, Experiments, Psychology, Self-Help. N.p., n.d. Web. 14 Apr. 2017.

StarTeach Astronomy Education. N.p., n.d. Web. 23 Apr. 2017.

Lockyer, J. Norman. “Ancient Egyptian Astronomy.” StarTeach Astronomy Education. N.p., n.d. Web. 21 Apr. 2017.

Contributor, Elizabeth Howell Space.com. “A Brief History of Mars Missions.” Space.com. N.p., n.d. Web. 23 Apr. 2017.

Agency, Zero. “How Collaboration Put Man on the Moon. – Zero Agency – Medium.” Medium. N.p., 30 Nov. 2015. Web. 23 Apr. 2017.

Hesse, Brendan. “We’re Going to the Red Planet! All 19 Past, Present, and Future Missions to Mars.” Digital Trends. N.p., 16 Oct. 2016. Web. 23 Apr. 2017.

Contributor, Elizabeth Howell Space.com. “A Brief History of Mars Missions.” Space.com. N.p., n.d. Web. 23 Apr. 2017.

Hesse, Brendan. “We’re Going to the Red Planet! All 19 Past, Present, and Future Missions to Mars.” Digital Trends. N.p., 16 Oct. 2016. Web. 23 Apr. 2017.

“Images | Mars Exploration Program.” NASA. NASA, n.d. Web. 23 Apr. 2017.

Gushanas, Timothy. “The Human Body in Space.” NASA. NASA, 30 Mar. 2016. Web. 23 Apr. 2017.

Gander, Kashmira. “How Architecture Uses Space, Light and Material to Affect Your Mood.” The Independent. Independent Digital News and Media, 16 May 2016. Web. 23 Apr. 2017.
Lehrer, Jonah. “The Psychology of Architecture.” Wired. Conde Nast, 14 Apr. 2011. Web. 23 Apr. 2017.

“Sign In: Registered Users.” Psychology during the Expeditions of the Heroic Age of Antarctic Exploration - May 18, 2012. N.p., n.d. Web. 23 Apr. 2017.

“Arctic Living.” C+S Engineer. N.p., n.d. Web. 23 Apr. 2017.

Harbaugh, Jennifer. “NASA Awards Top Three Design Finalists in 3D Printed Habitat Challenge.” NASA. NASA, 27 Sept. 2015. Web. 23 Apr. 2017.

NASA 3D-Printed Habitat Challenge. N.p., n.d. Web. 23 Apr. 2017.

Garner, Rob. “How to Protect Astronauts from Space Radiation on Mars.” NASA. NASA, 30 Sept. 2015. Web. 23 Apr. 2017.

Spector, Julian. “How to Build a House on Mars Using Only Stuff on Mars.” CityLab. N.p., 08 Jan. 2016. Web. 23 Apr. 2017.

Dunbar, Brian. “Fire Away, Sun and Stars! Shields to Protect Future Space Crews.” NASA. NASA, n.d. Web. 23 Apr. 2017.

Patrick L. Barry |, Patrick. “Plastic Spaceships.” NASA. NASA, n.d. Web. 23 Apr. 2017.

“How Will Living On Mars Affects Our Human Body?” Space Safety Magazine. N.p., 25 Sept. 2014. Web. 23 Apr. 2017.

Nosowitz, Dan. “Scientists Grow Vegetables On “Martian” Soil; Believe We Won’t Die From Eating Them.” Modern Farmer. N.p., 30 June 2016. Web. 23 Apr. 2017.

Q. Choi, Charles. “If Humans Go To Mars, Where’s The Best Place To Land?” Popular Science. N.p., 27 Oct. 2015. Web. 23 Apr. 2017.

Atkinson, Nancy. “Melas Chasma: The Deepest Abyss on Mars.” Universe Today. N.p., 24 Dec. 2015. Web. 23 Apr. 2017.

IMAGES

[1] Digital image. Https://olinuris.library.cornell.edu/parallax/sagan. N.p.,

[2, 8, 10] Digital image. Https://www.nasa.gov/image-feature/research-mathematician-katherine-johnson-1980. N.p., n.d. Web.

[3] Digital image. Dickson, Kieran. "Can Ridley Scott's 'The Martian' Convince Congress to Send Humans to Mars?" The Huffington Post. TheHuffingtonPost.com, 19 Aug. 2015. Web. 01 May 2017.

[4] Digital image. "Time For NASA To Double Down On Journey To Mars." Universe Today. N.p., 21 July 2016. Web. 01 May 2017.

[5] Digital images. Gracea.capobianco. "New Book, "South Pole," Chronicles Robert Falcon Scott & Team's Incredible Journey to Antarctic." Downtown Magazine NYC. N.p., 17 Feb. 2012. Web. 01 May 2017.

[6] Digital image. "Mesopotamian Astronomy." Babylonian and Persian History. N.p., n.d. Web. 01 May 2017.

[7] Digital image. Ponder, Jon, and Buck Banks | Apr. 30, 2017. "Terrible Deeds: Thousand of People Have Been Burned Alive in Christ's Name." Pensito Review. N.p., 06 Feb. 2015. Web. 01 May 2017.

[9] Digital image. Agency, Zero. "How Collaboration Put Man on the Moon. – Zero Agency – Medium." Medium. N.p., 30 Nov. 2015. Web. 01 May 2017.

[11,12,13,14,15] Digital image.Https://www.nasa.gov/image-feature/research-mathematician-katherine-johnson-980. N.p., n.d. Web.

[16] Digital image. Http://www.spacex.com. N.p., n.d. Web.

[17] SpaceX. "Home." SpaceX. N.p., n.d. Web. 01 May 2017.

[18,19,20] Digital image. Https://www.nasa.gov/image-feature/research-mathematician-katherine-johnson-1980. N.p., n.d. Web.

[20] Digital image. "NATGEO - Mars 2016 S01E01 - Novo Mundo." Bilik Video. N.p., n.d. Web. 01 May 2017.¬

[21,22,23] Digital image. "Free stock photo of black-and-white, depressed, depression." Free Stock Photos. N.p., n.d. Web. 01 May 2017.

[24,25] Digital image. Agency, Zero. "How Collaboration Put Man on the Moon. – Zero Agency – Medium." Medium. N.p., 30 Nov. 2015. Web. 01 May 2017.