Creative city design / Vol. 6, No. 1, 2023, 59-77

A Review of Physical and Environmental Components of Habitat Design on Mars

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Submit Date: 09 January 2023, Accepted Date: 11 March 2023

ABSTRACT

Given the interdisciplinary processes of designing a natural habitat for the crew in an extraterrestrial space such as Mars, the creation of a livable space habitat, which is compatible with technological requirements, goals of scientific missions, and human factors, is a major challenge to space architects and engineers.

Therefore, the present review study sought to detect and investigate the effective components of physical and environmental structures of the habitat design on Mars. According to the results, the human factor is considered the first important component in designs, and the main goal of all efforts is ultimately human travel and habitation in space. Besides, environmental components such as pressure, temperature, gravity, atmosphere, cosmic radiation, ice water, and seasonal and daily changes make humans comply with the most important technical issues in designing these habitats. Their types of structure and materials are important physical components that affect the space architecture of habitats on this red planet. According to the research findings, the use of materials from the surface of Mars or wind structures, the utilization of regoliths from the surface of Mars, or the chemical synthesis of carbon nanotubes, and also their construction in suitable places such as the crater of Hellas Planitia and lava tube caves are suggestions for the construction of a permanent habitat on Mars inspired by the proposed examples. Furthermore, combining existing options with new conditions such as installing wind structures in the protected space of caves can be a new approach to design and can be considered an intelligent option.

Keywords: *Space architecture, Mars, Environmental factors, Physical factors, Extraterrestrial habitats.*

1-Introduction

Earth is the only known world as a life refuge. There is nowhere else to call home. Humans evolve from something primitive to something less primitive over years. This evolution, which has created the basis of our life, forces humans to consider the future. Our needs and demands have increased with the acquisition of further

The future of mankind will be decided by the race between two competing human drives, one unleashing military power to compete for Planet Earth's finite resources, and the other organizing international cooperation to provide access to unlimited extraterrestrial resources [3].

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This manuscript is taken from Atieh Dezfouli's doctoral dissertation titled "Explaining the Basics and Principles of Designing Sustainable Settlements Based on Space Architecture on Mars" which is conducting according to the advice of Dr. Kamal Rahbari Manesh and Dr. Mohammad Mahdi Kheirikhah and supervision of Dr. Jamaleddin Soheili at the Faculty of Architecture and Urban Planning of Islamic Azad University of Qazvin.

NASA's Mars Reconnaissance Orbiter, ESA's Mars Express, and NASA's Phoenix Mars Lander confirm the presence of water ice on Mars [23] but it should be noted that many factors must be taken into consideration in sending humans to Mars. Even if Mars is apparently similar to Earth, this planet has completely changed thousands of years ago and it is now a deserted planet without any signs of life [4]. However, what caused Mars to become a cold desert planet with no signs of life is one of NASA's top mysteries. Therefore, the desire to explore and reach the unknown excites both governments and any private entity such as SpaceX and official space agencies, which can launch rockets, to go to Mars. Today's human is planning to go or even stay there. Therefore, it is now possible to reach Mars at the same time as The Magellan expedition in the Pacific Ocean [34].

There are a few possible solutions for the process of constructing human habitats on Mars. The first option is the spaceships carrying astronauts/scientists that go from Earth to Mars and they can their habitats. This approach is both costly and uncertain because the bigger the spaceship, the higher its cost, and there is no guarantee that the spaceship will not be damaged after a long journey and hard landing on the surface of Mars. The second option is to build suitable habitats that can be built before or after the arrival of the first human to Mars using modern technology and specialized robots, which is definitely an expensive approach that may be associated with many problems in the absence of direct human supervision. The issue of choosing suitable materials is also raised in this approach: What will be suitable local (Mars) construction materials? Transferring all materials from Earth to Mars will not be an economical solution. In addition to these two options, the third option can also be a suitable combination of the two. Therefore, even though the construction of habitats, and living on Mars have many technical and operational problems and solving these information and the rate of our information- and the technology along with it- has led to disasters such as war, overpopulation, pollution, global warming, energy crisis, deforestation, and all results of human expansion. As we become more intelligent, we will recognize that the earth will not be our refuge forever. American astronomer and scientist, Carl Sagan said: "The task of every human society is to travel in space, not just for space exploration or interest, but also for the most common imaginable act that is survival". Stephen Hopkins said: "Our population and the use of earth's finite resources grow exponentially in line with our technical ability to change the environment for good or bad. Avoiding crises in the next hundred years is hard enough. Don't think about the next thousands or millions of years. Our only chance for long-term survival is not looking at earth internally but expanding it in space" [5]. The present research reviews studies and analyzes and explains the challenges to planning for a sustainable habitat on Mars. The research results indicate that materials such as carbon nanotubes or graphene can be used in the habitat owing to the discovery of chlorinated hydrocarbon molecules on Mars .Mars is the main goal and priority for building extraterrestrial habitats. Even though the Earth is similar to its "sister planet" "Venus" in terms of its volume composition, size, and surface gravity, the similarities between Mars and Earth become more convincing during close scientific investigations. A Martian day is very similar to an Earth day in terms of duration. A solar day is 24 hours, 39 minutes, and 35.244 seconds on Mars. Mars has an area of about 28.4% of Earth's surface which is slightly less than the land area of Earth (that is 29.2% of Earth's surface). The radius of Mars is half of the Earth and only one-tenth of its mass. In other words, it has less volume (~15%) and a lower average density than Earth. Mars has an axial tilt of 25.19º, similar to Earth's 23.44º. Therefore, it has very similar seasons to Earth. Recent observations by designing human houses or habitats on Mars. In this regard, the second section mentions the studies in this field and examines the issues for the construction of extraterrestrial habitats or houses on Mars by explaining the upcoming challenges, and providing a suitable platform to enter the main discussions. The third section presents the research methodology and the fourth section presents the main findings. Space architecture, environmental and physical components affecting the construction of Martian houses or habitats, materials and models, and finally the improvement and development of these models in recent years for space projects, and their findings are among the topics discussed in this section. The fifth section presents the summary, conclusion, and suggestions.

2- Research background

Various studies have been conducted by researchers on space architecture in the last half-century. In the simplest definition, space architecture is the theory of designing NASA future researchers, evaluates various issues of space habitats, and the researchers' presentation of some valuable points. Various topics such as technical issues and challenges relating to the construction of space habitats, the architectural method of certain projects such as the Mars Direct project, the investigation of the system and life based on extraterrestrial plants, aerospace design, and the design and construction of analog space habitats, the way of adapting space habitats, protecting the crew's health and safety living in these places, environmental monitoring of water recycling and carbon dioxide removal, etc. are among important issues for investigation. Furthermore, Mars's natural and climatic conditions (environmental components), which can significantly affect the creation and development of multifunctional extraterrestrial habitats, are also studied and analyzed.

The second category presents are a group of scientific activities in the form of writing books or implementing academic projects problems is not an easy task, modern science and new construction technologies can help to choose the right path in executive actions by their identification, focus, and development. The main questions in the scientific debate about the habitats of Mars and other extraterrestrial planets have been merely physical, for example, "How much weight can a spacecraft carry to Mars?", or "How and where can humans live without spacesuits?", but the questions change more as life and mission on Mars become closer to reality. Before living on Mars, there are more than just physical measures that must be taken into consideration. The present study explains how designing space habitats on Mars must consider environmental and physical components before traveling and intending to stay on Mars. Given the lack of studies on the above-mentioned fields, we seek to use a review approach to answer the main research question of which environmental and physical components are effective in and building environments in space. Many works of space architecture have sought to design concepts of the orbiting space station and exploratory spacecraft on the Moon and Mars and surface bases for the world's space organizations, mainly NASA. In Europe, the International Space University is deeply involved in space architecture research. The International Conference on Environmental Systems annually holds various meetings about human spacecraft and human agents in space. The technical committee of space architecture has been established in the American Institute of Aeronautics and Astronautics. The emergence of space tourism has changed the landscape of space architecture work despite the historical pattern of large government space projects and conceptual design at universities. Some studies are mentioned in a table as follows.

According to Table 1, studies on space habitats can be classified into two distinct categories. The first category, which is mainly assigned to articles and studies of space habitats as the outcome of numerous studies by space scientists.

about the process of designing space habitats or designing laboratory devices that may take us to space one day . Therefore, each of these studies helps to clarify the real conditions of extraterrestrial

Table 1. An overview of studies on space habitats (source: authors)

Row		Author(s)	Year	Title	Theme
Articles and studies of NASA futurists	1	Marc M. Cohen [7].	2014	Space Habitat Design Integration Issues	Challenges and issues of construction of a space habitat
	2	Robert M. Zubrin & David A. Baker [8].	1996	Mars Direct: A Simple, Robust, and Cost-Effective Architecture for the Space Exploration Initiative	Mars Direct Project: A simple, robust, and cost-effective architecture for space exploration
	3	Robert Ferl, Raymond Wheeler, Howard G Levine, and Anna-Lisa Paul [9].	2002	Plants in space	Almost all scenarios for the long-term habitation of spacecraft and other extraterrestrial structures, including plants as an essential factor, support human life. This article studies life support systems based on extraterrestrial plants with a deeper focus.
	4	Marc M. Cohen [6].	2015	Mockups 101: Code and Standard Research for Space Habitat Analogues	Application of aerospace design methods to plan, design, and manufacture analog space habitats, the Mockups program, and simulators with a precise code and standard research with the aim at compliance to protect crew health and safety and find new ways to resist gravity with non-orthogonal structures and space architecture, indicating a new turning point in this development in which the gravity decreases.
	5	Van Alebeek“bachelor's thesis authored by a student at Eindhoven University of Technology” [5].	2014	Interstellar habitat: an architectural design of a habitat traveling through deep space	This thesis aims to bring architecture to a new level (space). Undoubtedly, living in space is associated with unique problems and possibilities, and it is interesting to examine it from the view of architecture. In space, our design principles need to be re-evaluated, and technology and materials will act as a new goal, but other issues such as life require information about conducting different fields (architecture, biology, society, philosophy, psychology, physics, and ethics).
	6	Robyn Gatens	2017	Environmental Control & Life Support Systems for Human Spaceflight	This research studies water recycling and carbon dioxide removal in environmental monitoring and helps future efforts to design lightweight and more reliable life support systems for future space missions.
	7	Jasleen Kaur	2019	Integration of Intelligent Health Monitoring Systems Into Inflatable Hybrid Structures	Achievement of improved system reliability and performance from habitat structure to life support systems, and human space missions require an integrated and reliable set of systems to live and work safely and efficiently in space.
	8	Bogdahn, Breaum, Breum, Larsen & Løvenskjold [1]	2019	In-situ Habitat Design on Mars	This study investigates and separates the habitats of Mars and Earth and identifies the physical and psychological consequences facing astronauts. Furthermore, this study along with the previous simulation, analog research, experimental research, and their analyses answers how these habitats should be designed to facilitate the crew's work and well-being on Mars.
	9	Praslova, Riabets, Shchurova, Zinovieva &Harbar [20]	2020	Functional Organization of extraterrestrial underground base on Mars	This study investigates the natural and climatic conditions of Mars, which can significantly affect the creation and development of multifunctional extraterrestrial habitats. The main natural and climatic factors such as high radiation, the lack of atmosphere, extreme temperature profile, and low gravity, which significantly affect the creation of Martian habitats on the functional architecture and organization levels, are also determined and investigated in this study.
	10	Neumerkel, Vecerdi, Meusburger [19]	2021	Design of an Autonomously Deployable Mars Habitat	This paper proposes a design for an independently deployable habitat for a long-duration manned mission to Mars. This habitat is considered in a way that it is transported in a compact form and it expands to a habitable volume by independent settlement after being placed on the surface of Mars. To this end, the study proposes the integration of several different kinetic structures.
	11	Delgado [2]	2021	Applications of Architecture for Future Martian Habitats	This article aims to analyze the problems that Mars has created for human life and suggests a solution by designing habitats. Life on Mars raises the question of how we can deal with high levels of radiation, cold temperatures, conservation of key resources, and human psychological effects.
	12	Alamoudi, Doheim,	2022	Humanizing Being on Mars: A Martian Colony	This project presents a comprehensive study to design a suitable habitat that can protect daily human life in an extreme

		Mohammed [33]			environmental situation. Therefore, several robotic missions are carried out on Mars to find a way to make this planet habitable and safe for humans.
A Relevant academic discipline, and related books and bulletins	13	Olga Bannova Nejc Trost Dr. Bonnie J. Dunb Larry Bel [25]	1987 until now	University of Houston SICSA'S ADMINISTRATION, TEACHING, AND RESEARCH FACULTY MASTER OF SCIENCE IN SPACE ARCHITECTURE Houston, Texas https://www.uh.edu	Students at the Sasakawa International Center for Space Architecture (SICSA) of the University of Houston create custom products for NASA during their training. Luke Schmidt, a graduate student in the discipline that is considered to be the only master's program in space architecture on earth, says: "The equipment in this lab may one day take us into space. "These are things that students design at SICSA usually in the order of NASA or its contractors."
	14	Sandra Haupilk-Meusburger & Olga Bannova [10]	2016	Space Architecture Education for Engineers and Architects Designing and Planning Beyond Earth	The authors of the book "Architecture education in space for engineers and designers" state in the abstract of their book: Space architecture as a field is relatively new. During a space architecture workshop, students complete their unique projects on natural housing systems to optimize individuals' safety and comfort under harsh and limited circumstances of space housing.
	15	Brand Norman Griffin (S.A.T.C) [11]	2018	Step-By-Step Process For Designing Weightless Space Habitats	Examining the step-by-step process of designing space habitats (specialized committee of space architecture)

exploration rovers in 2004 and 2012, followed in 2019 by the Insight lander. Currently, 6 active satellites orbit around Mars, with the primary purpose of studying the atmosphere. Private companies are also starting to take part in space exploration. SpaceX and Blue Origin were founded to reduce the cost and increase the safety of space flight and aim for near-future Mars exploration [12]. Traditionally, this discussion has been exclusive to mechanical and aerospace engineers with little participation of architects. However, if the commitment to establish a permanent presence on Mars is made, many challenges must be overcome through architectural design work combined with engineering. Space architects are eager to solve the real problems of modern extraterrestrial environments. They exploit the land to restore the found native conditions that are rapidly disappearing so that human civilization can one day remain there, take root, grow, and move forward. Therefore, it will be possible to expand life throughout the infinite space of the world, and space travel between planets will be similar to intercontinental travel on Earth, and thus

3-Materials and Methods

The present research was a simple review that focused on detecting and introducing the environmental and physical components of habitat design on Mars. Therefore, it sought to give proper answers to the main question of the research and analyze the results by reviewing books, articles, or projects related to the subject.

4- Research findings and discussion

1-4- The Astrotecture:

Humans live in a period without borders in every continent and environment on the planet at the beginning of the 21st century. The growth of societies, which dominate their environment, will stop and reach stagnation over time, and there is a need to create a new front. Wernher von Braun's Mars Project was the first serious study on the creation of the idea of life on Mars from the realm of imagination to the realm of practicality [24]. Since this date, there have been many discussions about the way of achieving this dream. Regarding nearby planets, NASA launched several

1- **Similarity**: This planet is similar to the Earth that we can walk on (there is a crust to step on and there is also gravity. This planet has a thin atmosphere rich in carbon dioxide with a temperature similar to ours, and a time of approximately 24 hours a day, and...)
2- **Proximity**: it is possible to reach it in 3 months.
3- **Hospitality**: It is more hospitable than our other neighbor, Venus (a surface temperature of ~500 ºC, very high pressure, acid rains, etc.), and it is even our only friend in the solar system (with high radiation and low pressure) if the atmosphere is not considered with its carbon dioxide.
4- **Possessing local resources**: Building materials can be obtained from its soil. This planet also contains water and enough daylight to feed energy production panels [27].

In addition to the above-mentioned cases, there are also players who have important scientific, social, and even functional roles and serious plans for this planet, including:
A. Public organizations: Official agencies with space exploration capabilities, especially NASA and ESA, are working on both robotic and manned missions. Since they largely use public resources, the conditions of their programs change depending on political conditions. **B- China Space Agency**: This agency, which tried to land the first research robot on Mars in 2020, is established in a special center in the Gobi Desert and researches surface missions.
C- Private institutions: SpaceX Crew-5, which has the most serious plan for Mars, is a private company that was established with the motive of transferring the burden of space exploration from the public to the private sector and opening new economic fields. A transport rocket with a stainless steel body is the first example of the Starship project [27].

human worries about the lack of living space will disappear. The space architecture approach combines engineering thinking with criteria related to habitability and human factors, such as those observed in industrial design and architecture, in addition to including other fields such as biology and basic sciences.
In the early 1970s, several architecture students expanded the scope of graduate thesis defenses on space station concepts. At the end of this decade, NASA's interest in building a space station revealed the need for architectural thinking, leading to aerospace support contractors' consideration of recruiting an architect, and eventually, the space station opened up more doors, including NASA architects, the broader contractor community, and academia collaborating on the emerging field of "space architecture." There is now a growing international community of architects and industrial designers working across the space domain. They are involved in all fields of space projects and mission development, including robotic Mars rover and probe design, lunar and Mars base design, launch facility planning and construction, mission capacity definition and management, underwater and simulated gravity testing, system engineering, space mission control support, and design and construction of natural habitat of the Earth's environment. Space architecture is basically a generalization of earth architecture.

2-4- Physical components of the importance of Mars

Mars is one of the 5 planets visible to the naked eye and has attracted human attention beyond recorded observations that started with Galilei. Owing to studies by spacecraft, we have obtained important information about the atmosphere with carbon dioxide, the traces that may have carried life, and its bluish sunsets. The physical factors which make Mars an attractive destination for us are as follows:

establish a permanent presence on Mars and the construction of a large and permanent habitat begins, construction methods must be carefully taken into consideration. Relying on completely-built settlements on the earth is an unsustainable strategy unless there are truly significant advances in transportation technology [3].

Scientists determine seven natural factors (environmental components) that can effectively affect the functional organization of man-made extraterrestrial multifunctional habitats, as discussed below.

3-4-1- Atmospheric pressure

Mars has a very thin atmosphere. Even at the lowest point on the planet, the atmospheric pressure is about 100 times lower than the 1013 millibars at sea level on the earth. This means that the main structural challenge on Mars is the internal pressure of all inhabitants. The severity of this problem can decrease if the internal pressure reaches lower than the sea level pressure. Potosi in Bolivia is the most similar city to the atmospheric conditions of Mars on Earth. At an altitude of 4000 meters, the atmospheric pressure is 620 millibars or about 60% of the sea level pressure. As humans have lived in Potosi for several generations without harming their well-being, the habitat on Mars can also be subjected to a pressure of 620 millibars without increasing the risk for immigrants [3]. Even if low-pressure habitats are built in the highest cities on the earth, the structures of the habitats must still be able to resist the immense external force of 60 kPa (8.7 psi) (Figure 1).

3-4- Effective components in the environmental structure of the Mars habitats

There are various special reasons for human presence on Mars. Finding life in another world is probably the most widely accepted reason. Furthermore, humans should conduct basic scientific research to obtain new knowledge and information about the origin of the solar system and its history, and use it in research on the use of Martian resources to strengthen life-sustaining systems. In this regard, Mars is the ultimate "urban laboratory" where acute conditions lead to questions about basic assumptions about the way of building a livable society. Ultimately, Mars can be a valuable project for many countries working together. Over years, space travel will become commonplace and commercial companies will emerge, but innovative missions can only be done through cooperation between governments. Mars is the most Earth-like planet in the solar system. It is the only planet that we can imagine sending humans to in the near future. This planet has seasonal changes and almost the same length of day and night. Mars has all the necessary resources for sustaining life, but the Moon lacks many biological elements that will need to be imported from the Earth. A common statistic is that there is water in it. Furthermore, the moon has a circadian cycle and a duration of 27 days. Therefore, Mars is the only place in the solar system with the capacity and potential to become a new living place for humans (Figure 1). If the decision is made to

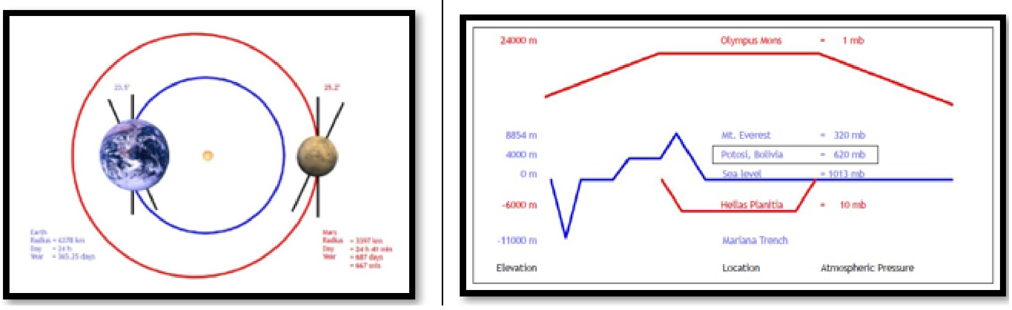


Figure 1. Comparison of some environmental parameters: size, orbit, rotation, altitude, and atmospheric pressure on Mars (red) and Earth (blue) [3].

3.4.2- Gravity

a surface gravity of about 39% of Earth's resistance which does not make construction easier. The loads on any human habitat resulting from the pressure difference between the internal and external states are larger than the weight of necessary materials to enclose the space (Figure 2). Therefore, has a dynamic atmosphere despite its thin atmosphere. Seasonal dust storms, which can surround the entire planet, are the most important phenomena. Low atmospheric pressure makes the force of winds relatively negligible, but dust causes wear and tear of any unprotected materials. (Figure 2)

Mars is important structural problems on Mars are to keep the building down and maintain it against gravity like on Earth [3].

3-4-3- Temperature, atmosphere, and dust

Mars is about 1.5 times farther than Earth on average, making it colder. The average temperature is about -60 to +20 ºC. Mars has an atmosphere with a thickness of 1% of the Earth. Without the separation of the thin layer of the atmosphere, the daily temperature changes are much greater. Mars

Mars is about six times smaller than Earth and with a lower total density; hence, it has

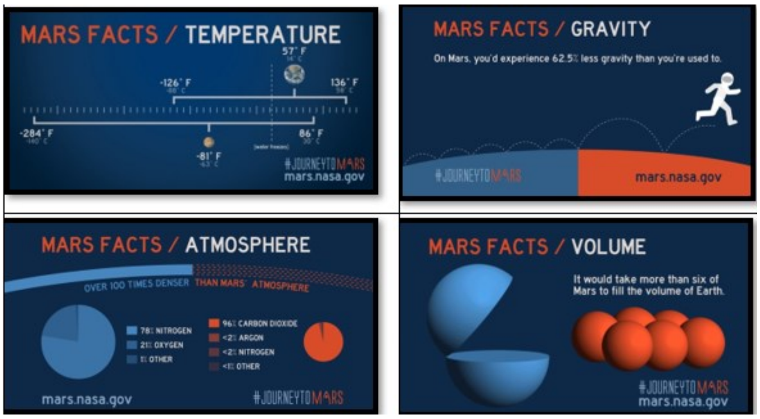


Figure 2. Comparison of gravity, temperature, volume, and atmosphere on Earth and Mars [13]

themselves from the first two types of radiation by being in habitable space covers in dimensions of about one meter of regolith..." [8]. Serious thought must be given to shaping this planet to establish a long-term human presence on Mars. The protection of the planetary magnetic field, which Mars does not currently has, is an important requirement for such formation. Earth's magnetism helps protect the planet from the potentially sterilizing effects of cosmic rays and also helps preserve the atmosphere, otherwise, it is destroyed by large solar storms as they pass over the planet. Mars has small patches of residual magnetic field on the surface, but they are located in the southern hemisphere and are

3-4-4- Magnetic field and radiation

Radiation is the final important feature of Mars. There are three different types of radiation on Mars that should be taken into account; first, the solar wind as a stream of charged particles that are constantly emitted from our star; second, cosmic rays. These rays are created from the explosion of stars in our galaxy and the explosions of the solar system from all directions; finally, solar flares. The sun periodically emits large clouds of charged particles that spread throughout the solar system [11]. All habitable spaces must be protected from ionizing radiation that reaches the surface of Mars. "Mars immigrants can protect magnetic magnetosphere at planetary dimensions. (Figure 3)

not large enough to protect the planet or an immigrant [14]. If Mars is to be a long-term home for human life, it will likely require the protection of an artificially-constructed

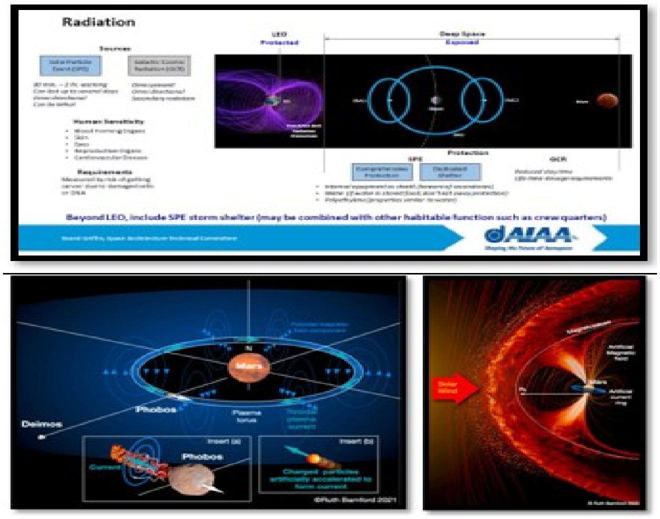


Figure 3. Radiation and magnetic field [14]

Table 2. Comparison of some environmental components on Earth and Mars [13]

	EARTH	MARS
Average Distance from Sun	93 million miles	142 million miles
Average Speed in Orbiting Sun	18.5 miles per second	14.5 miles per second
Diameter	7,926 miles	4,220 miles
Tilt of Axis	23.5 degrees	25 degrees
Length of Year	365.25 Days	687 Earth Days
Length of Day	23 hours 56 minutes	24 hours 37 minutes
Gravity	2.66 times that of Mars	0.375 that of Earth
Temperature	Average 57 degrees F	Average -81 degrees F
Atmosphere	nitrogen, oxygen, argon, others	mostly carbon dioxide, some water vapor
Number of Moons	1	2

3-4-6- Mars soil

The Martian soil is **3-4**

the third natural factor and its parameters are similar to Earth's soil. Plants can also grow in Martian soil. A large amount of carbon dioxide in the atmosphere gives the opportunity to produce vegetarian food, as well as water and oxygen from local sources, but this issue still requires

-5- Ice waters

The ice water on the surface of Mars is the next factor. Since pure water cannot exist in liquid form on this planet, it turns into vapor due to the low pressure of ice [28]. Therefore, if Mars is supposed to be a long-term habitat for human life, the issue of water supply and its storage should also be taken into consideration.

winter; hence, this issue should be borne in mind [29].

4-4- An important human component in Martian habitats

Another important issue that should be considered in the design of habitats is the characteristics of the human body in weightless status (Le Corbusier's modular human proportions model).

The space architecture approach combines engineering

additional experiments or artificial soil [29].

3-4-7- High seasonal and daily temperature changes

The next final factor includes the high seasonal and daily changes in temperature and amount of solar energy. The surface temperature of Mars is much lower than on Earth and is -63ºC on average. The surface temperature may reach +30 ºC at the equator at noon and -153 ºC at the poles in

weight measures should be taken for human factors and design based on human activities. A broader understanding of human-related physiological and physical effects based on design strategies and perception of the way of designing for mitigation purposes is critical to the success of future exploration missions [11].

thinking with criteria relating to habitability and human factors, such as those cases observed in architecture and industrial design, in addition to including other fields such as medicine and science. It is important to integrate human factors and other human aspects in the design process by organizational parties (Figure 4). Regarding the approaches to the design of current facilities and space systems, more

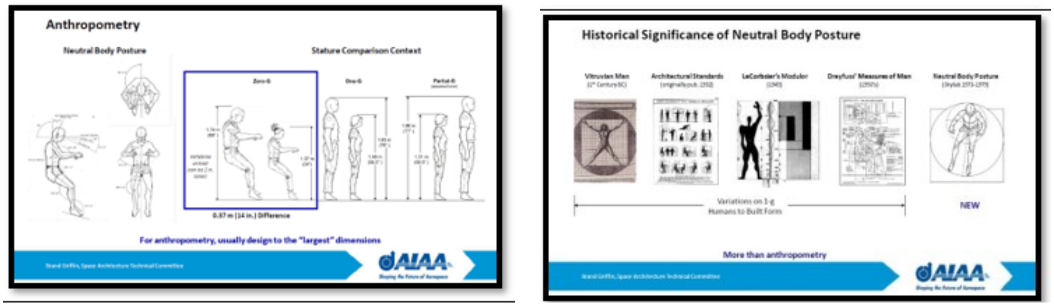


Figure 4. The human body characteristics in weightlessness and presenting a new model of modular proportions [11]

Regoliths and rocks are the most abundant materials on Mars. The entire planet, except at the poles, is covered with nothing but regolith and rock. Bruce Mackenzie suggests that the first immigrants can produce bricks using regolith [18]. The masonry structure of a compact robust building is very strong and it is chosen because it is the only always-available resource on the surface of Mars; however, it has low tensile strength. It is necessary to use a masonry structure together with

5-4- Effective components in the physical structure of Mars habitats

In a general classification, we can divide the effective factors in the physical structure of the Mars habitat into two important categories, the type of structure and the type of materials used in these structures, which will be mentioned in the following.

5-4-1- Masonry structure

(1984) regarding the construction of buildings on the moon inspired by the design of desert architecture and based on SuperAdobe, is also based on this approach. (Figure 5)

another system, which can withstand pressure through tension, to give the ability to see space outside the habitat and the possibility of accessing the surface. The idea presented by Nader Khalili, a famous Iranian architect, at the NASA seminar

Figure 5. Suggestions for using masonry structures in the space habitat [3]

detailed conceptual design for such a structure was performed by NASA in the late 1990s. This project basically aimed to create a transit vehicle to carry six individuals to Mars; hence, the name "Transhub" was used for the portable habitat [3].

5-4-2- Inflatable structure

The advantages of inflatable structures are as follows: They are very light and have the greatest weight-to-volume advantage compared to rigid-walled habitats (Figure 6). Furthermore, these structures can expand in small dimensions and be pre-tested on the earth. The idea of using tensile fiber structures in space works has been created since the 1960s [11]. The first

Figure 6: The use of inflatable structures in the space habitat [11].

complementary plans have been proposed for it over two decades [6]. The constituent layers include humidity control, destruction of volatile organic compounds, the use of algae and cyanobacteria to remove CO_2, production of O_2 and food supplements, and processing of urine and gray water using solid/black water treatment. (Figure 7)

5-4-3- Water walls

A highly reliable interplanetary habitat was presented in the second half of the 1990s for long exploratory missions with the potential of water walls. It is a largely passive system based on osmotic processes, focusing on the unique and weird properties that the inner water protective layer has for the provision of micronutrients and radiation protection, and several

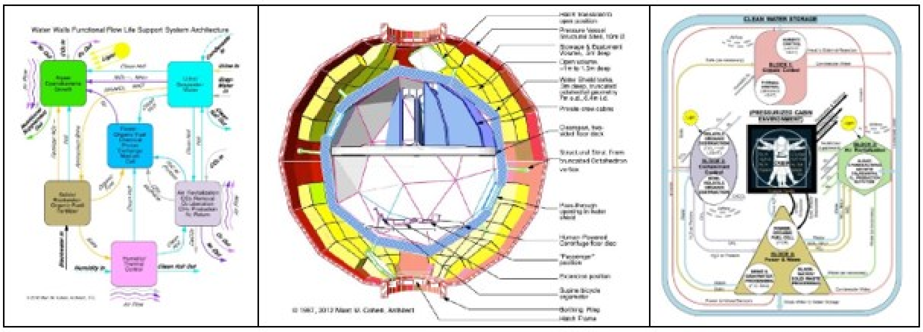


Figure 7. Using water walls in the space habitat [6]

According to the above-mentioned cases, we can now summarize the effective environmental and physical factors in designing space habitats in the diagram below.

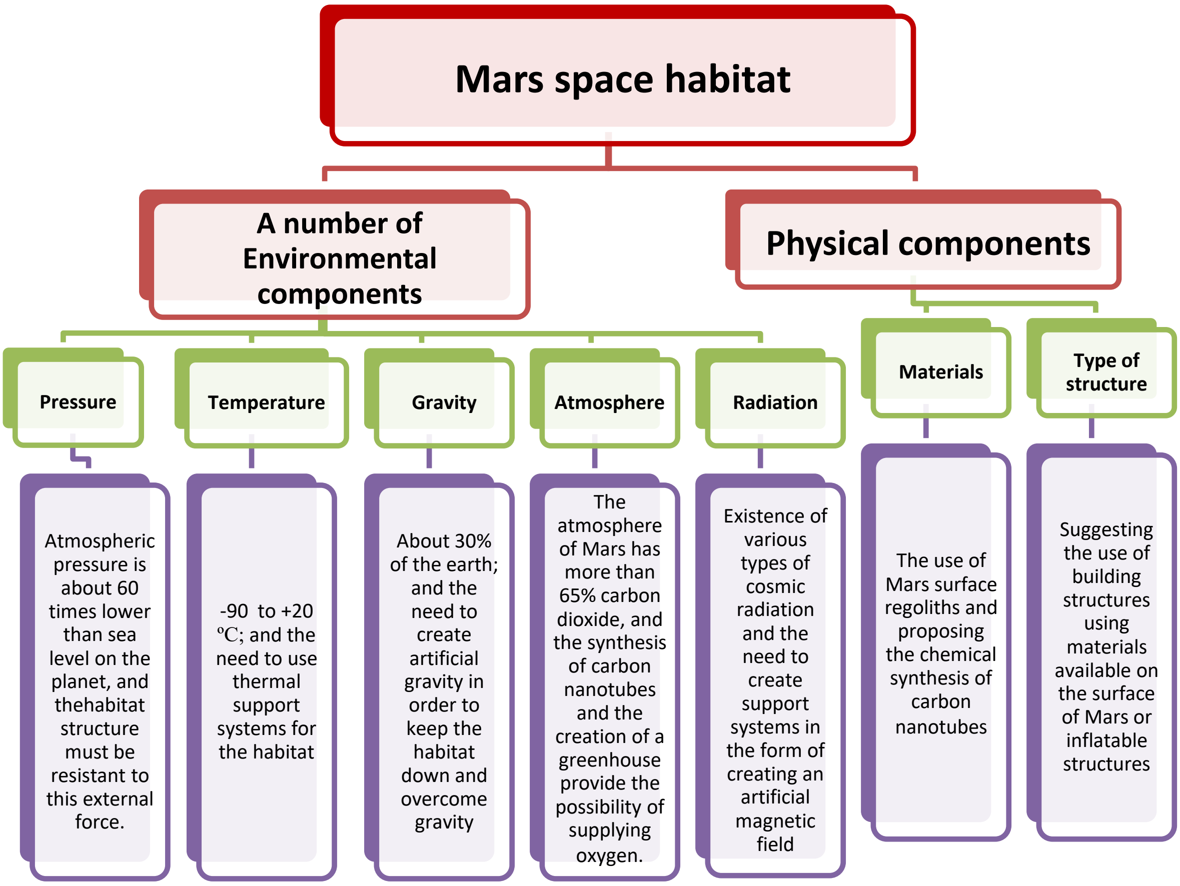


Diagram 1. Presenting a conceptual model of solutions to challenges in designing a space habitat (source: authors)

kilometers away from Earth and unable to breathe air. Therefore, the most suitable places to settle on Mars can be listed as follows to cope with the unfavorable environmental conditions:

6-4- Suitable places for building Mars habitats

High radiation and low pressure are two challenging situations for humans who want to build a place to live on the Red Planet, apart from being millions of provide the possibility of creating independent chambers and the possibility of air conditioning owing to their structures [32].

3. Crater of Hellas Planitia: Since this depression area is located at a lower altitude than the normal surface of the planet, it has a high atmospheric pressure for Mars and is beneficial for us. The high pressure of the environment can help us easily meet the sealing conditions in the structure that is going to be built.

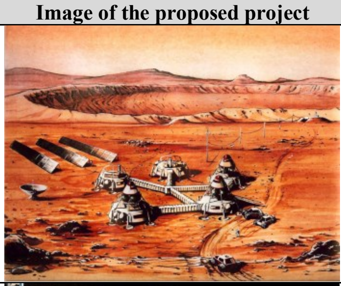
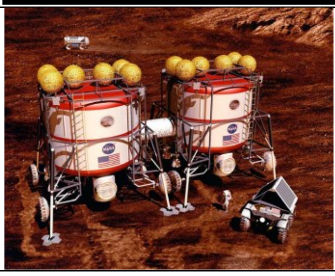
7-4- A summary of the proposed models for space habitat by futurists

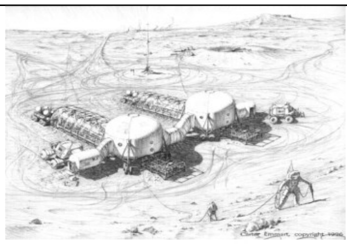
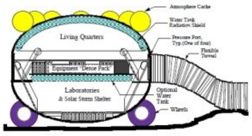
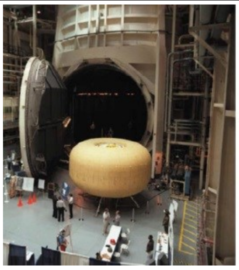
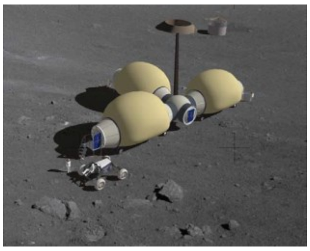
The models proposed by the researchers have been examined for about a quarter of a century according to the following table:

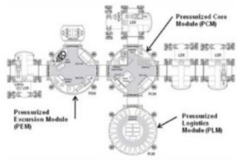
1- Tropical regions: Due to the creation of natural caves in some parts of volcanic activity (e.g. around Arsia Mons volcano) [30], using the natural topography to one's advantage is an old tactic. It is also possible to obtain geothermal energy in tropical regions. Hiding behind layers of rock and building inside caves may be proper options to be protected from high surface radiation on this planet [31].

2- Lava tube caves: Caves, which are formed by the flow of lava masses and are extended in the form of tubes located under the surface of Mars, are also suitable places for life because the surface deformations, which seem to be cracks in the roof inside these tubes, protect against radiation, and also their interior spaces theoretically

Table 3. A summary of the proposed models for the habitat on Mars during about a quarter of a century, 1989-2015 (source: authors)

Row	Authors	Year	Image of the proposed project	Key features of the project
1	Vladimir M. Garin [15] (www.astrotecture.com)	1989		The first concept for the design of habitat on Mars, which was developed at NASA's Ames Research Center, proposed multiple Apollo command landings at the same time, with fuel tanks installed separately on each module and these habitats connected by inflatable tunnels for crew movement.
2	Prairie View A&M University [26]	1992		An image of a habitat using regoliths on the surface of Mars, which is a combination of basic and buildable concepts and has been developed as the first idea of NASA.
3	Kent Joosten [15] (www.astrotecture.com)	1993		NASA's basic Mars mission is to build a two-story habitat including crew quarters and a greenhouse space for life support with a pressurized system (Zubrin's canned fish idea) and it uses local resources to provide fuel and oxygen for the return trip.

4	Strategies for Mars interpretation of the Joosten, Weaver, and Duke Designed by Marc Cohen [7]	2014	 	The project of the Mars scientific laboratory as a refuge to cope with the solar storm includes a facility laboratory and an agricultural laboratory where plants grow in similar status to Mars, including the use of rocks for soil and the provision of water from the Martian atmosphere. Flexible pressurized tunnels between modules connect each habitat at the "mezzanine".
5	Borowski, Dudzinski, McGuire [15] (www.astrotecture.com)	2002	 	"TransHab" is an interplanetary vehicle on the way to Mars, deployed as an inflatable module with a rigid central core, somewhat similar to a sponge tire. In this model, the crew room is located on the middle deck and the gallery and rest room are located on the lower deck. These structures have the task of expansion in small dimensions and can be pre-tested on the earth.
6	Scott Howe [15] (www.astrotecture.com)	2008		This habitat is designed as a mobile robot that has a self-assembly system and can unload and reload large cargo like the habitat itself. The pressurized Mars rovers in the "Mobile Home" concept look more like insects than other mobile bases. The frontal lobe resembles a compound eye. The module has a body-wrapped radiator for waste disposal.
7	Cadogan, Scheir [15] (www.astrotecture.com)	2010		During the first decade of the 21st century, NASA, industry, and academic architects and engineers introduced new concepts and technologies for a lunar-Mars habitat. The first serious and technical proposals for lunar inflatable habitats began to emerge in the first half of the 1990s. The modules form a base cluster around a spherical node and each one is equipped with an airlock. This example is simulated in Antarctica.
8	Kriss Kennedy [16]	2012-2015		In recent decades, the use of architectural advances and integration of habitats has led to improved and diverse modeling for spatial structures. Evolved examples of inflatable structures similar to cylindrical and donut-shaped (rotating wheels) designs equipped with platforms around central cores for the expansion of inflatable structures have been approved by most NASA researchers.

9	NASA drawing [17]	2012	 	At this stage, NASA researchers have presented various models of improved systems of inflatable structures for habitats on the moon or Mars. Interconnected and ring-shaped models (rotating wheels) in which functional elements in various forms such as crew areas, training departments, recreational facilities, medical equipment, research laboratories, and greenhouses are embedded next to the control and command room. The spiral ladder or staircase in the central core provides a platform for installing the air expansion unit, and the flexible tunnels connect different parts.
10	“2023 Roadmap” Credit: MarsOne	2015-2023	 	The "MarsOne" project follows the strategy of detecting habitat landers and payloads that were outlined in NASA's first Mars rovers. The lander's cargo and crew modules are apparently based on the SpaceX Dragon capsule. The 15 lander modules are connected through tunnels like beads on a string. Along with the main idea of this design, capsules are also installed for growing plants which can be useful for the crew as a part of a biological life support system.

properties of materials are completely changed and the materials show properties that are very surprising and strange in nano-dimensions. Another interesting feature of nanotechnology is its highly inclusive and multidisciplinary nature [21].

8-4-1- Carbon nanotubes and their benefits for space projects

Carbon is the basic material of all living structures on earth. This element can be found in all living structures. Carbon is the dark matter resulting from the burning of all organic matter or living structures. Carbon can be found in different forms in nature, such as graphite, which is a soft black substance, and diamond which is hard and shiny. Undoubtedly, the reason for these amazing differences in two substances with the same atoms is the arrangement of carbon atoms next to each other. In the 1990s, the development and progress of nanotechnology took place at a faster pace. The first active companies in the field of nanotechnology started working at the end of this decade. Nanotubes are materials with a diameter of up to 100 nm. In 1991, a very important nanostructure, called carbon

8-4- Nanotechnology and its place in the design of Mars habitats:

Nanotechnology is a science about the precise engineering of dimensions on the scale of a billionth of a meter. This science has now left the research mode and entered the competition as a political and commercial strategy; hence, it can be called an industrial revolution in the last century. The use of nanotechnology has decreased the volume of devices, costs, and processes and increased productivity. Nanotechnology will soon become a fully-functional word. This technology is one of the latest technologies that will definitely affect many industrial and manufacturing sectors in the long term. It is integrated with technologies such as electronics, biology, chemistry, robotics, and aerospace, resulting in the creation of new ways to solve problems in products by nanostructure micro-components. Nanotechnology means material engineering in atomic-molecular dimensions and thus building materials with completely different properties in nano-dimensions. The most important feature of nanomaterials is that the leading to the creation of methods for the production and reproduction of advanced electrical circuits and arrays of biomaterials for biological research. (Figure 8)

nanotube, was discovered. Carbon nanotubes are sheets of graphite that have become tubes. Carbon nanotubes have unusual properties in terms of strength, and thermal and electrical conductivity [21].

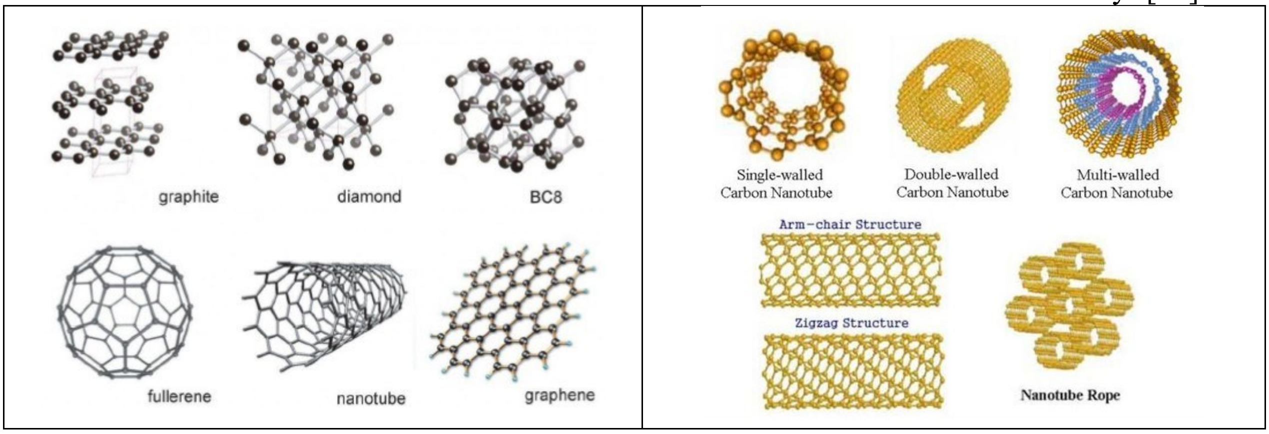


Figure 8. Types of carbon structures and various patterns of carbon nanotubes [21]

technology, carbon dioxide is used to produce carbon nanotubes and it is very useful to prevent global warming. The absorption of carbon dioxide on electrolytes produces heat. This process is exothermic and causes more carbon dioxide to be absorbed. Pure oxygen is one of the side products of this process, which is cheaper than carbon nanotubes and can be used for many industrial processes [22]. Some amazing properties of these nanomaterials and their use in the construction of spacecraft are summarized as follows. (Diagram 2)

The successful development of synthetic carbon nanotubes will lead to the evolution of engineering and architecture. Carbon nanotube structures can currently reach the length of thousands of meters, while they are much stronger than steel. This will be a significant acceleration in the development of space stations with the availability of space elevator technology." [3]. Carbon compounds form the basis of life on earth, and the carbon-nitrogen cycle supplies a part of the energy produced by the sun and other stars. This technology has been used in Alberta, Canada, and has managed to reach the XPRIZE finals. In this

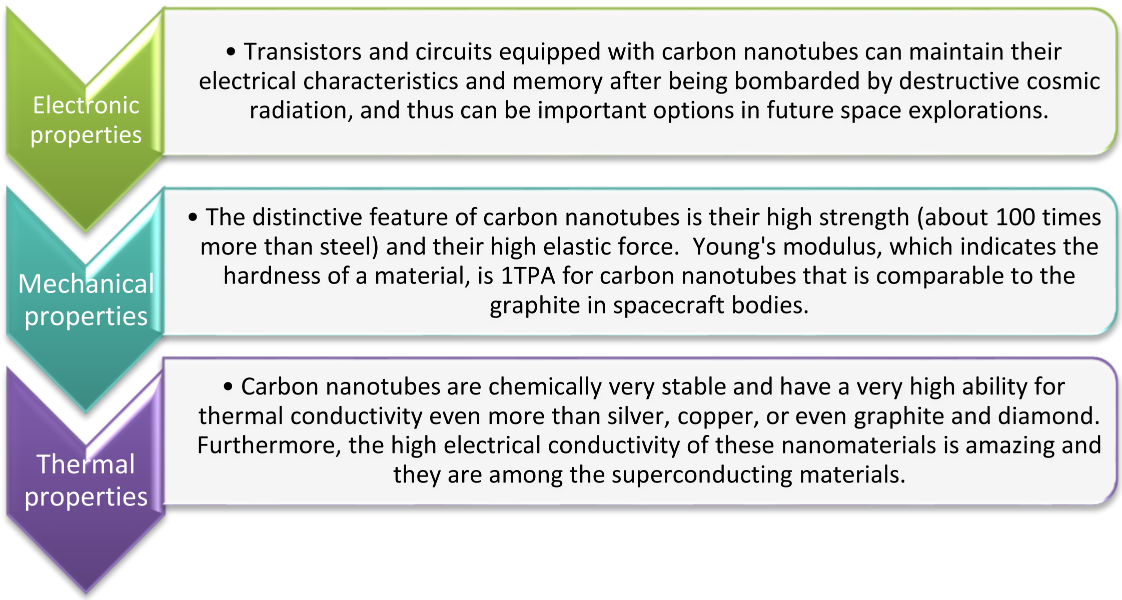


Diagram 2. An overview of the properties of carbon nanotubes in space exploration (Source: authors)

crew's movement or creating a habitat as a mobile robot that has a self-assembly system and can also unload and reload large cargoes.
The results of the present research, which showed a significant difference in terms of subject and findings from previous studies, referred to all effective factors in designing extraterrestrial habitats, and it was thus considered an innovation, indicating that the use of nanotechnology and the successful development of synthetic carbon nanotubes could be a suitable accelerator for the development of space stations with the availability of space elevator technology.

The above-mentioned content indicates that there are several factors in designing Mars habitats that have been identified and used in plans by humans over time. Human factors are among the most important factors, which should be taken into consideration at every stage of the process of extraterrestrial habitat design by considering that people are beyond the "elements" of a system and are its reformers and creators. Furthermore, environmental factors such as pressure, temperature, gravity, atmosphere, radiation, ice water, and seasonal and daily temperature

5- Conclusion

Numerous studies have been conducted on space travel, settlement, and civilization. Futurists, scientists, and architects from different disciplines have all shared their views on living in space. Space architecture is a relatively new discipline in which these views include ideas and concepts about explaining the way people live and behave in space. However, information about the conditions and constraints of extraterrestrial space together with architectural arguments are considered valuable because these conditions will still exist in the future. The results of this review indicated that even though the Earth is more similar to "Venus" in terms of volume composition, size, and surface gravity, it also has important similarities with Mars, which has made humans think of traveling and even staying there. When we focus on the construction process of human habitats on Mars, there are a few solutions and proposals that have been presented during numerous studies such as building habitats in the form of fuel tanks, which are installed separately on each module and are connected to each other by wind tunnels for places such as the crater of Hellas Planitia and the lava tube caves for building a permanent habitat on Mars inspired by the proposed examples presented by future researchers. In response to the question in the introduction of the present research and with a review of the relevant sources, it is argued that even if there is necessary infrastructure for living on Mars, the construction of a permanent habitat inspired by the proposed examples is possible according to human, environmental, and physical components. Even though existing studies and designs are far from implementation, they do not mention the use of a building system without exception. Combining the available options with a suitable combination of conditions can also be vital and a new attitude in design. For example, installing wind structures in the protected space of caves is also a smart option that can be considered because we must use what we have in the harsh conditions of Mars in the most efficient combination.

changes, can be the most important environmental components that made humans comply with some other the most important technical issues in designing these habitats. Therefore, the livability of these habitats without observing the key factors greatly increases the risk of setting up a sustainable life supply system based on comfortable life, and biological reproduction with the ability to produce food and recycle air and water. In addition to the above-mentioned components, there are some other effective components in the physical structure of habitats that affect space architecture. Types of structure and materials are among the most important issues which have always been taken into consideration by designers and made them look for suitable structures and optimal and economical materials. Therefore, the authors suggest using materials from the surface of Mars or wind structures, applying regoliths from the surface of Mars, or the chemical synthesis of carbon nanotubes, and building them in suitable

References:

1. Bogdahn, C., Breaum, A., Breum,H., Larsen,H & Løvenskjold,M.(2109). *In-situ Habitat Design on Mars*. Humanistisk-teknologi gruppe-nr: v1924809575.
2. Delgado, D.J.(2021). *Applications of Architecture for Future Martian Habitats*. AIAA Southeastern Regional Student Conference. April 5-6.
3. Petrov G., "*A Permanent Settlement on Mars",* Master of Architecture Thesis at the Massachusetts Institute of Technology, February 2004.
4. Kent, L. (2019, December 6). *What we now know (and still don't) about life on Mars*. CNN. Retrieved from https://edition.cnn.com/2019/12/06/world/life-on-mars-evidencescn/index.html.
5. Van Alebeek, S. C. M, *Interstellar habitat: an architectural design of a habitat traveling through deep space*. (Author). 31 Dec 2014.
6. M. Cohen, M., Astrotecture, Palo Alto, CA, USA 94306, "*First Mars Habitat Architecture",* AIAA SPACE 2015 Conference and Exposition, 31 Aug-2 Sep 2015.
7. M. Cohen, Marc, "*Being a space architect*, Courtesy of NASA, 2014, pp 78-80.
8. Zubrin, R., and Wagner, R., *The Case for Mars: The plan to settle the Red planet and why we must*. Free Press, 1996.
9. Ferl, R.; Wheeler, R, Levine,H & Paul, A,*"Plants in space",* Current Opinion in Plant Biology 2002, 5:258–263, © 2002 Elsevier Science Ltd.
10. All rights reserved."Published online 21 March 2002"
11. Haupilk-Meusburger, S. & Bannova, O. *"Space Architecture Education for Engineers and Architects Designing and Planning Beyond Earth*", 2016.
12. Griffin, B. N., *"Step-by-step process for designing weightless space habitats",* Space Architecture Technical Committee (SATC) ,November, 2018.
13. Alhilal, A.; Braud, T. C.; Hui, P.,*" The Sky is NOT the Limit Anymore: Future Architecture of the Interplanetary Internet",* IEEE Aerospace and Electronic Systems Magazine, v. 34, (8), article number 8799061, p. 22-32, August 2019.
14. https://mars.nasa.gov
15. Bamford, R.A. " *How to create an artificial magnetosphere for Mars''*, 09.023 Received 12 July 2021; Received in revised form 7 September 2021; Accepted 14 September 2021.
16. http://www.astrotecture.com
17. Kennedy, K., "*Lessons from TransHab: An Architects Experience*" AIAA Space Architecture Symposium, 10-11 October 2002, Houston, Texas, AIAA 2002-6105.
18. Henze, S., "*Module for Lunar Base Project, Command and Control Center*", Sasakawa International Center for Space Architecture, University of Houston College of Architecture, Spring 2012.
19. Mackenzie, B., "*Building Mars Habitats Using Local Materials"* p. 575 in The Case for Mars III: Strategies for Exploration. Stoker, Carol ed., American Astronautical Society: Science & Technology Series, V.74, 1987.
20. Neumerkel, R. W.E., Vecerdi, M., Meusburger, S.H. (2021). *Design of an Autonomously Deployable Mars*

Habitat. 50th International Conference on Environmental Systems. 12-15 July.

21. Praslova, V., Riabets, Y., Shchurova, V., Zinovieva, O., Harbar, M. (2020). *Functional Organization of extraterrestrial underground base on Mars*. International Journal of Innovative Technology and Exploring Engineering (IJITEE). Volume-9 Issue-5, March.
22. Sabu Th., Yves Grohens, Y. B. P., 1st Edition 2019, *Industrial Applications of Nanomaterials*, Elsevier.
23. International Organization for Standardization (ISO), 2015. *Nanotechnologies–Vocabulary–Part 2: Nano-objects*. ISO/TS 80004-2: 2015, Retrieved 8 January 2018.
24. Tithi, K.N. (2017). *Mars Habitation: Design for extreme condition*. Ms. Thesis. Miami University. http://hdl.handle.net/2374.MIA/6146
25. Von Braun, W., *The Mars Project*. Bechtle Verlag, 1952.
26. NASA. *Man-Systems Integration Standards*, NASA-STD-3000, Rev. B., 1, 1995.
27. NASA. *Mars Reference Mission*. NASA Special publication 6107, 1992. Prairie View A&M University
28. Özdemir, K. (2020). *Building a home in Mars*. Future, technology and architecture.NO 45. PP 39-45. In Turkish.
29. Williams, M. (2015), "*Mars compared to Earth",* Universe Today corporate website, available at: www.universetoday.com/22603/mars-compared-to-earth/ (accessed 11 February 2023).
30. Williams, D. R. (2018), "*Mars Fact Sheet*", National Space Science Data Center. NASA, NASA corporate website, available at: https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html (accessed 10 January 2023).
31. Cushing, G. E. (2012). "Candidate Cave Entrances on Mars." Journal of Cave and Karst Studies, 74:1: 33-47.
32. Appelbaum, J., Flood, D. J.(1990). "*Solar Radiation on Mars*." Solar Energy, 45:1: 353-363
33. Cushing, G .E. et al. (2007). "*THEMIS*
34. *Observes Possible Cave Skylights on Mars*." Geophysical Research Letters, 34:1, 18.
35. Alamoudi, M.A., Doheim, R., and Mohammed, M.F.M. (2022). *Humanizing Being on Mars: A Martian Colony*. Civil Engineering and Architecture 10(3A): 19-26, DOI: 10.13189/cea.2022.101303.
36. Chaplin, Joyce E. (2013). *Round About the Earth: Circum navigation from Magellan to Orbit*. (New York: Simon & Schuster (36).