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Terraforming Mars: A Strategic Framework for Sustainable Colonization and Expansion

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Abstract: The prospect of Mars colonization is becoming increasingly feasible, with multiple national and private entities preparing for human settlement on the Red Planet. To ensure long-term success and avoid stagnation, as seen with the Moon, a clear Master Plan is essential. This paper outlines a phased development strategy, beginning with initial outposts and progressing toward full-scale terraforming, ultimately transforming Mars into a habitable second home for humanity. A unified Martian Constitution and cooperative governance could facilitate collaboration among diverse stakeholders. Additionally, the technological advancements required for terraforming will drive innovation across multiple industries, benefiting both Earth and future space exploration. The success of this endeavor hinges on careful planning to avoid the environmental and social mistakes of Earth while creating an optimized, sustainable Martian ecosystem.

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1. Introduction

After recent declarations of newly elected President Trump, backed by Elon Musk as consultant, it seems that Mars missions and colonization could be a closer and feasible event. But to avoid what happened with the Moon that after over half a century since final visit there was no follow up despite the important improvements in technology during such period. There are already several interested players for Mars colonization, not only NASA or Space x but also China, and hopefully India the EU, Russia and more. But for each one of them, to obtain permanent results, the most important issue is to have goals and a Master Plan as main instrument to obtain them. We believe in fact that soon there will be several settlements on Mars due to the numerous national and private players with space access technical or economical capabilities that would consider Mars in their expansion plans for different reasons ranging from scientific research, territory possession, national pride, business opportunities

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or just for profit. They may want to retain their national or company identity while developing their Martian plans. The only factor that could unify all settlements on Mars, could be a common Martian Constitution and the Terraforming of the planet since such activity would involve all players. Even if not all settlements would want to participate economically to such plan, everybody will have to accept the future global conditions. A potential federation of all Martian settlements, cities or colonies could be the best solution to deal with planetary dimension plans that may supersede local authority in Favor of global common conditions. in a developed Martian economy and society as needed for a growing local population requirements, different cities and territories as well as activities would flourish on Mars , due to location, type of population, opportunities and other while Mars terraforming would be the catalyst for exponential expansion of the planet economy and population with a rush to Mars fuelled by the potential wealth of an entire planet at disposal. With the final goal of Terraforming, an operation that may take decades, even centuries, Mars would become a twin Earth as far as territory is considered and will offer equal opportunities in an entirely new scale and environment. While such project may become the biggest one in humanity history it will also generate millions of high-end jobs here on Earth, expanding the entire economy. A million and more people community on Mars, could be economically justified, due to the hostile environment, distance from our planet and other disadvantages, only if the final goal is a major one such as Terraforming to modify the planet itself to be suitable to terrestrial life. Mars Terraforming will also create entirely new technologies, having to deal in a different planet with entirely different conditions than on Earth. All fields would be interested from construction, mining, mineral processing, health care, even governance and more. The creation of such new technological base would be precious for future expansion in the solar system. At the same time, we must avoid doing on Mars the same mistakes as on Earth, pollute the planet, mishandling its resources, create blight and poverty. Our society must utilize the Terraforming opportunity of an entire planet to design such new environment to support a human friendly ecosystem, with the best of our capabilities. The second home for humanity must be physically, socially and economically designed to optimize its capabilities and avoid past mistakes. That is the real challenge of Terraforming Mars and the reason that carefully crafted plans must be implemented.

2. Scenarios

In order to define the future development of Mars it is important to establish where we stand now in the space development process that started with the first probes and promise to create, through Terraforming, a second house for humanity. We can subdivide future progress in space by dividing phases of accomplishments through successive steps of achievements.

To reach interstellar travel capability, a logical future development of our society we can consider the following steps.

- ***Phase 1 Pioneering Age:*** The first phase of space exploration began with the launch of the Soviet satellite Sputnik in 1957, marking the dawn of human activity beyond Earth. This period has been characterized by rapid advancements, including human spaceflight, robotic planetary exploration, and the establishment of the International Space Station (ISS). However, space activities have largely remained limited to low Earth orbit (LEO), with only a few deep-space missions to the Moon and Mars. Technological advancements in rocketry, communications, robotics, and space infrastructure during this period laid the foundation for future endeavors beyond Earth's immediate vicinity.
- ***Phase 2 The Beginning:*** The second phase marks a renewed focus on crewed deep-space missions, with a return to the Moon as a steppingstone for Mars exploration. NASA's Artemis program, China's lunar ambitions, and private space initiatives aim to establish a sustainable presence on the Moon, enabling resource utilization and testing technologies for long-duration space habitation. Simultaneously, the first crewed Mars missions will focus on reconnaissance, survival strategies, and the establishment of initial outposts. These early bases will serve as critical hubs for scientific research, resource extraction, and logistical support for future expansion. The success of this phase will depend on advancements in life support systems, in-situ resource utilization (ISRU), and efficient transportation methods between Earth, the Moon, and Mars.
- ***Phase 3 Consolidation:*** As technology matures, the human presence on Mars will evolve from temporary outposts to self-sustaining cities. This phase will witness the construction of permanent settlements, supported by local industries such as mining, agriculture, and energy production. The development of a Martian economy, driven by space-based industries and interplanetary trade, will encourage further investments and innovations. A critical aspect of this phase will be the initial steps towards terraforming,

including atmospheric modifications, controlled greenhouse gas release, and microbial engineering to make Mars more habitable. Coordinated efforts among various national and private players will be essential to ensuring a structured and sustainable approach to planetary development.

- ***Phase 4 Operational**:* With the successful establishment of Martian cities, humanity will enter an era of full-scale solar system development. Colonization efforts will extend beyond Mars to asteroids, moons, and other planetary bodies, enabling large-scale resource extraction and settlement. Advanced terraforming techniques will be implemented, not only on Mars but also on select moons and planetary surfaces where underground or enclosed habitats could be developed. Space industries will flourish, contributing to a self-sustaining space economy that reduces reliance on Earth. Innovations in propulsion systems, fusion energy, and artificial gravity will facilitate deeper space missions, preparing humanity for the next phase of expansion.
- ***Phase 5 Interstellar Travel:* The** final phase in this framework envisions the transition from a solar system-based civilization to an interstellar species. By this stage, breakthroughs in physics and engineering—such as faster-than-light travel concepts, nuclear propulsion, or even space-time manipulation—will be required to overcome the immense distances between stars. Generation ships, cryogenic stasis, and self-replicating robotic probes may serve as precursors to true human interstellar travel. The establishment of self-sustaining colonies within the solar system will act as steppingstones for deep-space missions, ensuring that humanity is not confined to a single planetary system

For our paper, we will consider successive steps from Phase 2 to Phase 4

At such level of technology humanity must reach same progress in other fields such as eliminating diseases as a cause of death, breakthroughs in rejuvenation technologies, extended life spans, cloning, out-of-womb births, and brain-computer interfaces.

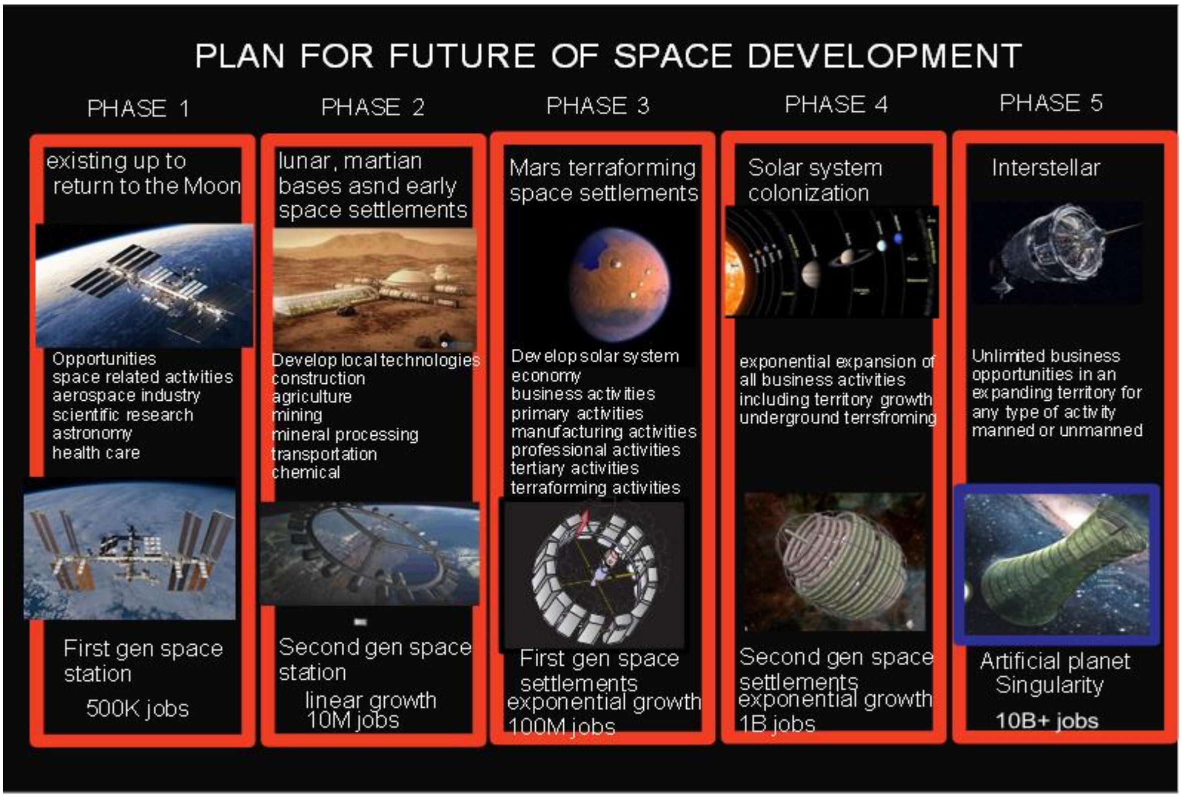

Figure-1 Plan for Future Space Development

3. The Martian Development Master Plan

At the moment our society is going to enter Phase 2 of its space development activities including the return to the Moon and missions to Mars. Starting with the first manned mission to the red planet it will be necessary to include it in a more general plan. Its location must be selected with the goal of future development, ease of access, presence of underground water, acceptable climate, resources available will be parameters for such choice. Since the players involved will be several national space agencies and private enterprises, some with their own equipment, others purchasing the trip, start sending manned missions and creating outposts and bases on Mars will be their first activity. Their primary goal was not only to take a hold onto the planet and several other reasons previously described but mostly claim and occupy territory that in the future may prove valuable. Several bases will be created in different parts of the planet, due to location, accessibility, rich and valuable minerals presence, water abundance and other factors multiplying human presence on the planet. In the following pages we will define, for each future phase, main technologies to enable Mars development.

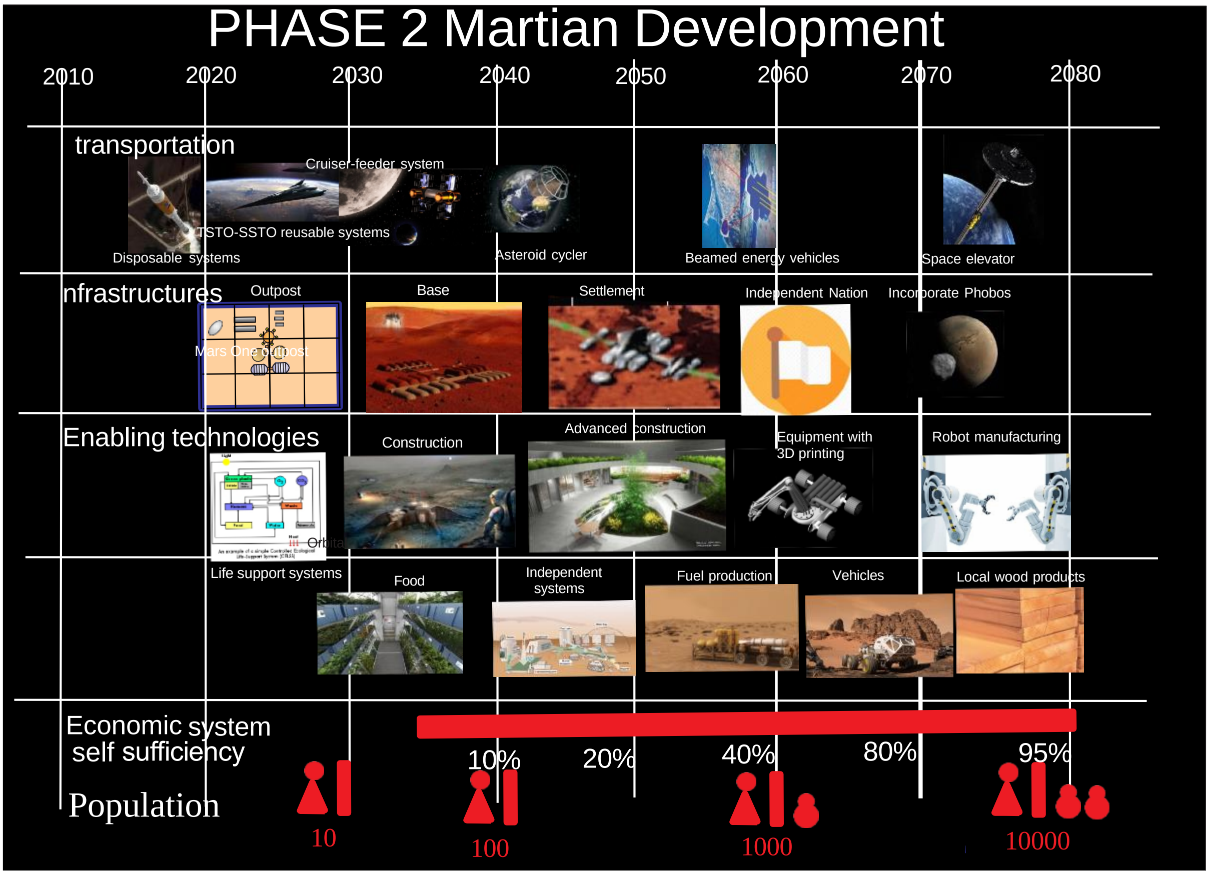

Figure-2 Phase 2: Martian Development

4.2. Goals for Phase 2 of Space Development

The general and most important goal for Mars development, as outlined in this proposal, is to Terraform Mars to create a second home for humanity for millions, even billions of people, to complement terrestrial limitations. To achieve this general goal our proposal must include several conditions that we must consider as limited but necessary secondary goals to reach the major one. They can briefly be visualized in the following chart.

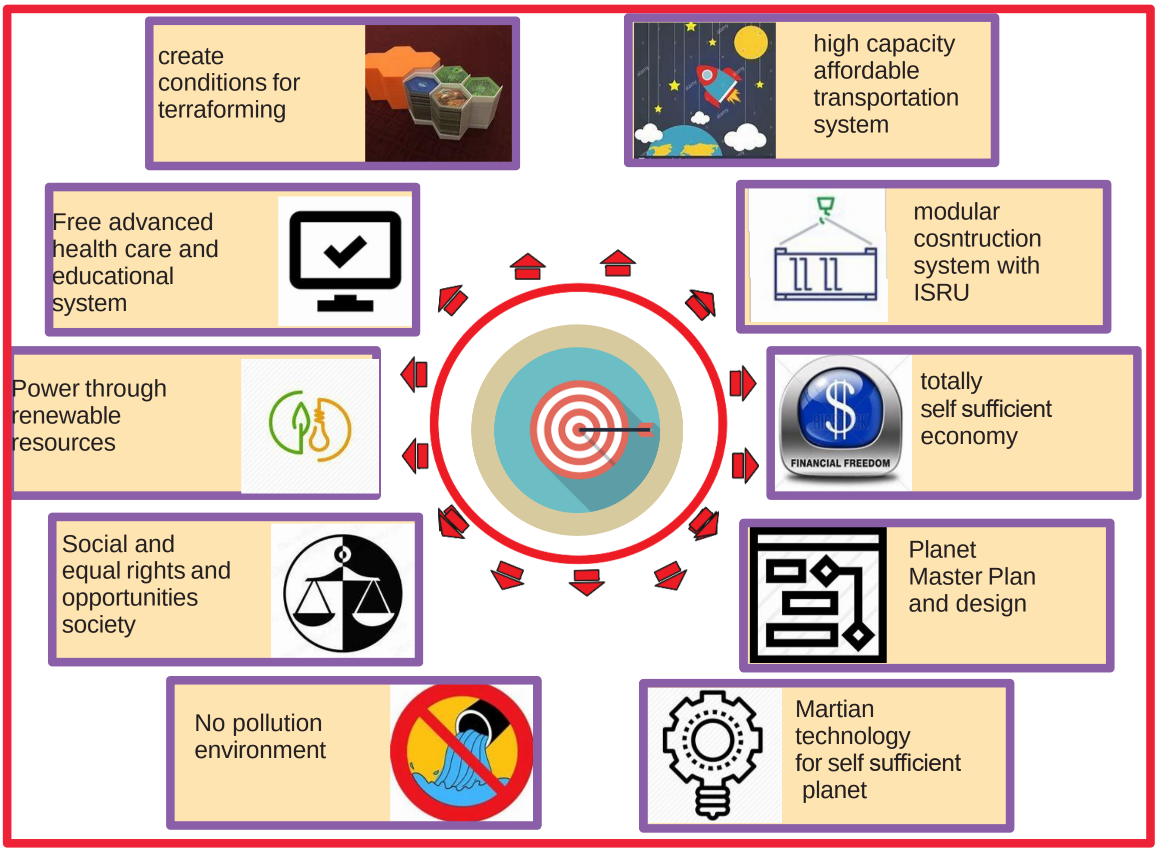

Figure-3 Goals for Mars Development

While these conditions are essential and necessary to proceed with terraforming, such goal must be implemented also through a planet redesign activity that will not only change the planet features at random but following an optimized landscape design for its future human occupation and utilization.

Landscape features, water bodies, high and lowlands must be redesigned to suit the Master Plan and human needs. A TransNet transportation network system to transport water, minerals, cargo and passengers, integrated with a new city planning philosophy called Symbiosis, separating physically the natural ecosystem but integrating it functionally must be part of the Plan.

4. Phase 2 Space Transportation System

A future population of thousands of settlers on planet Mars means that a totally new, efficient, low cost and high-capacity transportation system must be active between Earth and Mars. Considering that windows opportunities are effective every two years a new system must be created to assure the high quantity of passengers that will travel between the planets. Like the transatlantic ships that carried thousands of migrants between Europe and América in the second half and first half of 20th century, the cruisers to mars must contain thousands of people for the long nine months trip. The ships must also have $1g$ gravity, be self-sufficient for food and life support systems, power and fuel. The best solution would be a cycling ship, denominated cruiser, between the two planets supported by feeders at their vicinity to transfer passengers and cargo.

The cruiser with a few hundred passenger capacity, similar to a space settlement, in a beaded thorus shape, to generate artificial gravity by rotation around a central hub. Such vehicles would be composed of modules attached to the ring with the several functions needed for transportation (hub, food production, feeder port, health care, maintenance, life support system etc.) assisted by a feeder system to carry back and forth passengers between the surface of the two planets and the modules with passengers, cargo, agricultural and manufacturing levels to support the crew and passengers.

The feeders will consist of ring-shaped vehicles, carrying cylindrical containers in the middle and engine and fuel in the ring part for the short trip between the cruisers in space and ground bases.

A capacity of around 100 passengers each is provided in a circular shaped seat arrangement for several levels. In this way a totally reusable system will be operative. Such a system could be expandable when necessary. To further self-sufficiency in the future an expanded cruiser will utilize deflected small (20,30 m diam) asteroids and comets for water and materials needed.

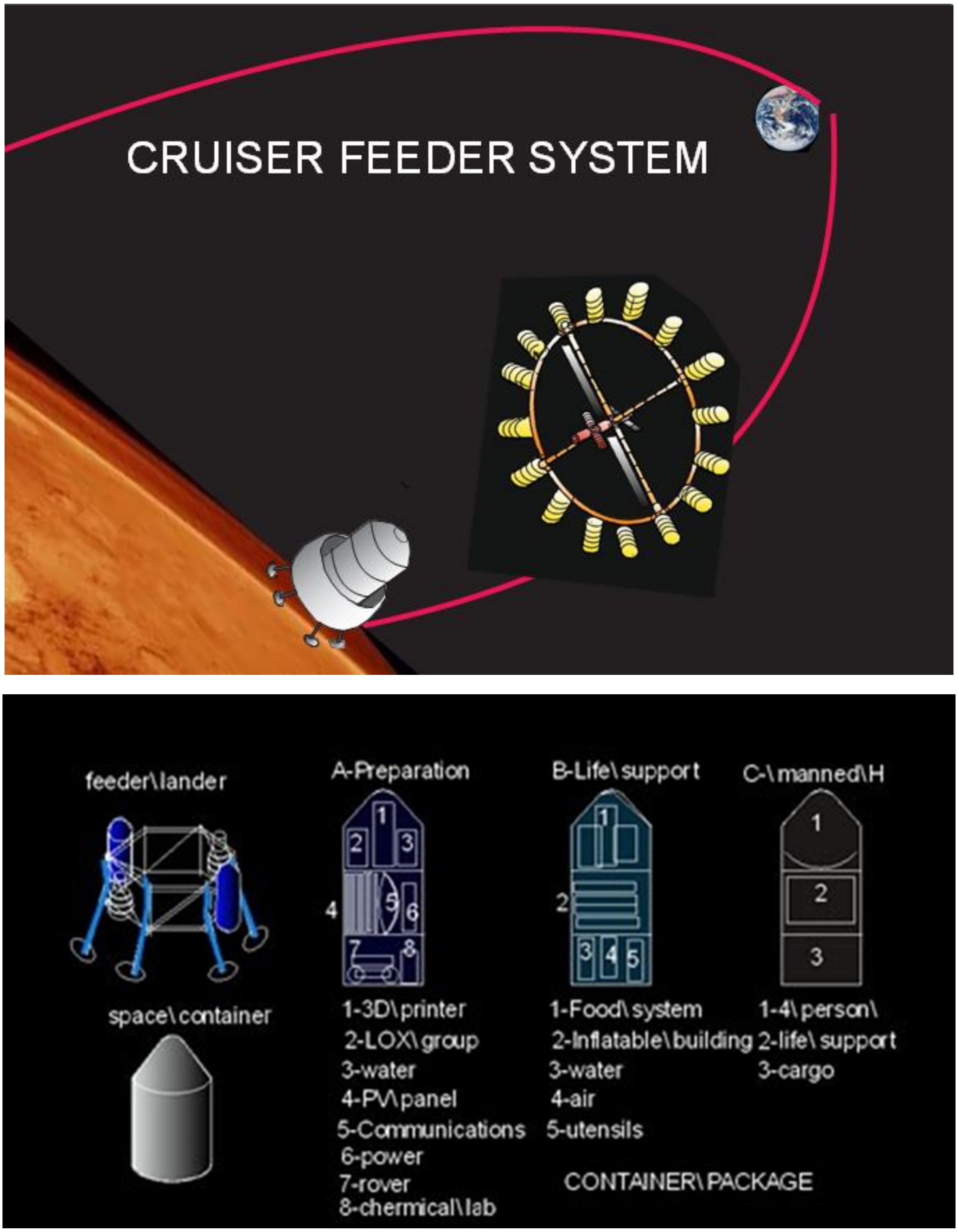

Figure-4 Cruiser Feeder System

The Ring system would guarantee transportation between the ground (Earth and Mars) and the cruiser while it is in proximity to both planets.

A container system is included in carrying passengers and cargo. They can transfer the entire container to the cruiser and the ground, each one with specific functions. In the image is shown a container system for the first mission to Mars, designed to create a permanent outpost for the crew.

The interplanetary transportation system will be based in a cruiser feeder vehicle combination on a cyclical Earth- Mars trajectory with settlement-based cruisers to transport the high numbers of settlers traveling**.** Land bases with spaceports and Phobos way station will be included in the system

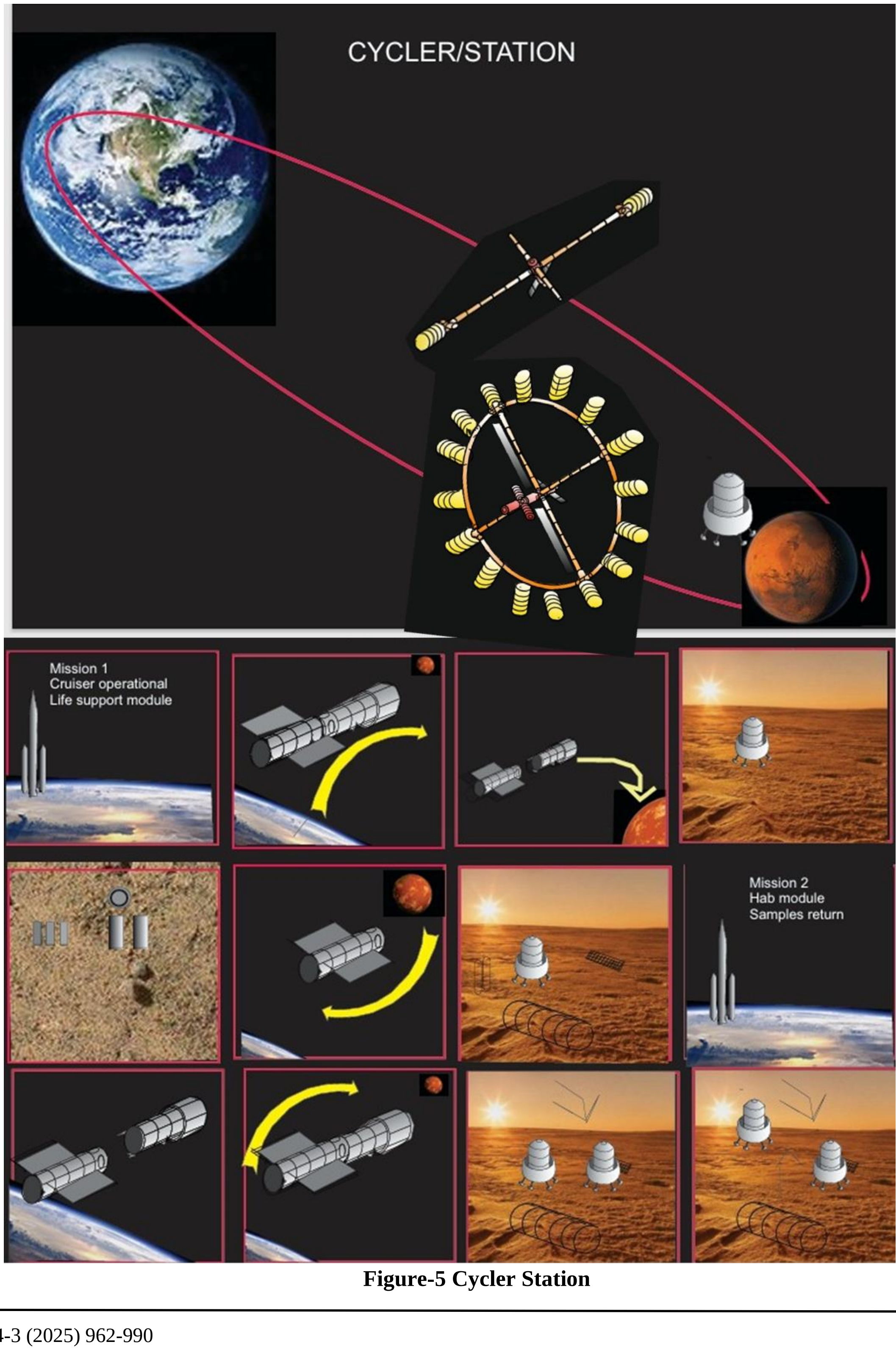

Figure-5 Cycler Station

Considering the complexities and risks of a Martian mission for a crew that must guarantee nearly three years of survival in good conditions, absolutely non comparable with previous lunar missions, such an outpost must be operational before the arrival of the first human crew to Mars.

In the figures are shown the main requirements for the first Martian outpost. They are:

Power generation

Solar power should be obtained by a photovoltaic system flower or panel shaped located in the vicinity. For additional guarantee and emergencies, a compact nuclear generation system should also be available.

Water production Water will be in constant need. Considering that any mission may last years on the planet, the outpost should be located near an underground ice available source. Such water would be extracted, tested and made available before human arrival.

- Air production
- Food production
- Fuel production
- Health care
- Waste recycling
- Resources prospecting mining and processing
- Habitat

Communication system

Following the outpost, as the Martian population keeps growing the outpost, designed for no more than 20-30 people, will be transformed into a base for several hundred people.

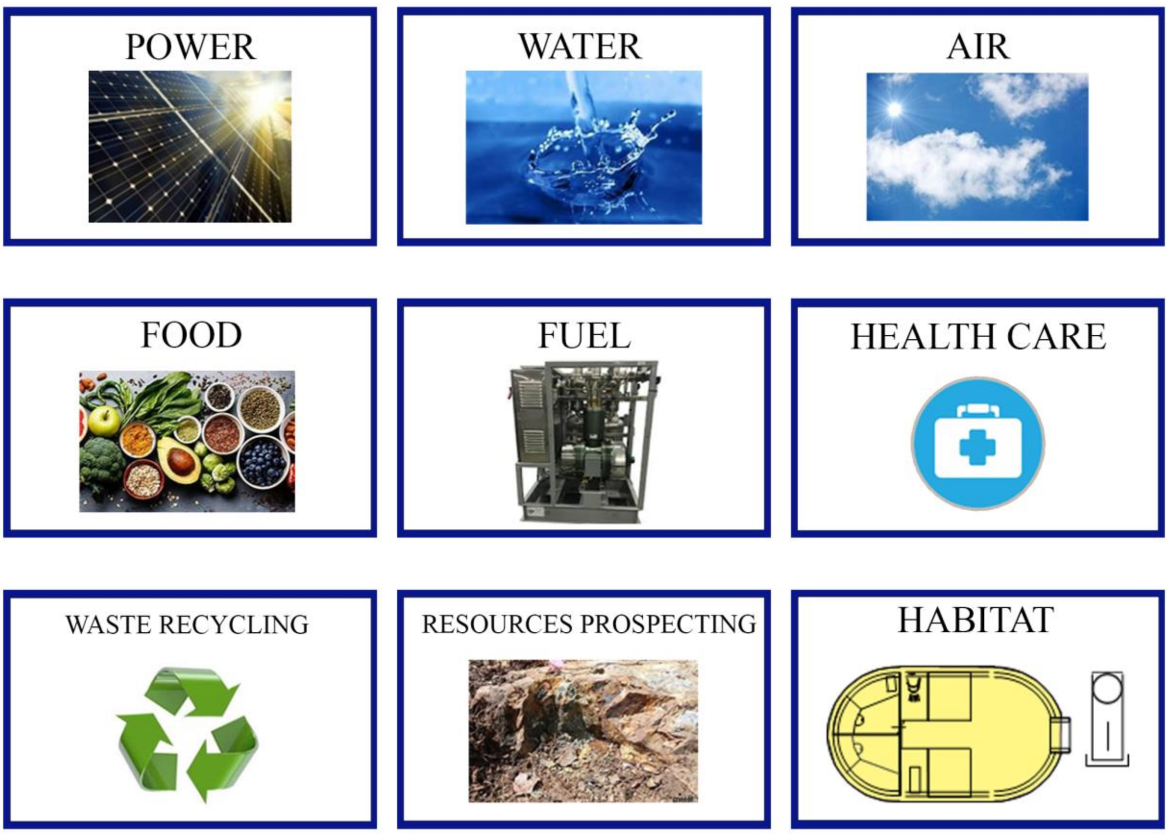

Figure-6 Requirements for Martian Base

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Following the first manned mission in the late 20s, several organizations sent missions to the red planet for several reasons. Most outposts, during time developed into bases and later in settlements to support a growing population and activities. We can imagine slow initial population growth, as shown in the chart, with increased expansion in later decades as per our chart. But the real catalyst for a population in the millions in such hostile and distant conditions is the terraforming of the planet. Its conversion to terrestrial standards and its related activities that would need thousands of personnel a, human and robotic together with the required equipment.

Only such a goal, and its rewards in terms of prime real estate, would mobilize big quantities of people. In accordance with our alternative 2 of the Martian scenario several bases and settlements would multiply in the planet, with different people, nationalities, scopes and goals while interplanetary transportation will become low cost and allow big quantities of passengers from our planet. To at tract settlers some organizations enacted a Martian homesteading plan, that would give Martian land and financing for equipment to terrestrial families willing to settle on mars and develop its land, both for mining opportunities or agricultural Such plan, after terraforming will at tract millions of settlers and change the face of the planet.

ACTIVITY	2030	2060	2100
Transportation	5	500	10K
Life support	10	1000	100K
Health care	5	500	30K
Food processing	5	2500	50K
Research	5	500	100K
Hab assembly	5	5000	200K
Fuel production	3	30	30K
Mining		500	50K
Mineral processin		1000	50K
Manufacturing		5000	50K
Assembly		5000	100K
local transportation		500	50K
science		500	150K
Maintenance		3000	300K
business		1000	100K

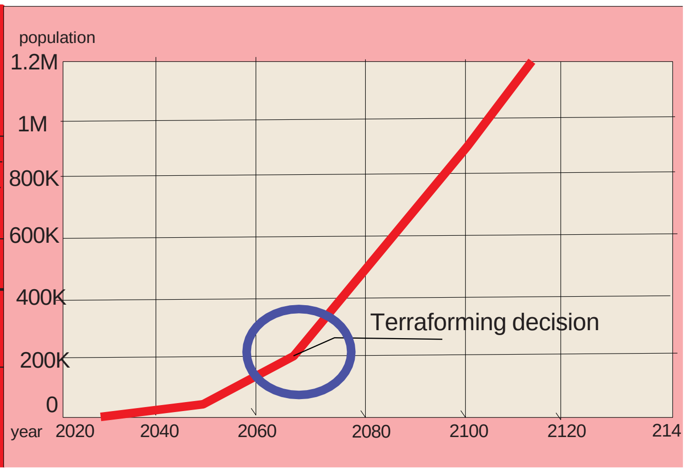

Figure-7 Martian Population Trend

In this chart showing the population divided by skills and numbers for the pre-terraforming phase and after such decision, in the 60s, we can visualize the important population increase due to that. Since a self-sufficient planetary community in order to support Martian activities, scientific research, Manufacturing and other activities on Mars an adequate number of people with different skills and genetic diversity must be present. For age and gender groups we can assume a population composition, at the end of the initial phase as follows:

Single males 30%, single females 30%, families 40% of which 70% with children

For the following phase the population age will change to a more homogeneous group while initial settlers will age, and new Young families will increase as settlers in the terraformed planet. The population expansion is directly related to business development, and it will keep growing to fuel an expansive economic system.

5. Mars Transportation System

An efficient, fast and distributed transportation system is the key for Mars development. Such a network will be a vital connection for all settlements and transport needed utilities, such as water, raw materials finished products as well as cargo and passengers to support local economies. To fuel the Martian economy a miriad outposts, settlements, cities will be operational, most of them with specialized activities in a more complex scenario.

A transportation system network will be based on the following assumptions:

- Minimize earth movements compared to more conventional ground-based systems
- Concentrate on all systems in a single (cargo, pax, utilities, water)
- Self-sufficient power wise based on locally renewable sources for power generation
- Based on prefabricated components that are easy and fast to manufacture and install and columns, with variable heights manufacture on site through 3D printing with local concrete.

- Powered by mag-lev systems for fast travel time
- MarsNet or Martian transportation system will connect major settlements and create a planetary level network as progress is made in Martian development. Furthermore, such a system would create a water network connecting most settlements with that precious resource

While such a network will be utilized for connecting small distances in the beginning, long range transportation will be guaranteed by rocket powered shuttle vehicles, during terraforming process it will cover the entire planet. n this chart shows the population divided by skills and numbers for the pre-terraforming phase and after such decision, in the 60s, we can visualize the important population increase due to that. Since a self-sufficient planetary community in order to support Martian activities, scientific research, manufacturing and other activities on Mars an adequate number of people with different skills and genetic diversity must be present. For age and gender groups we can assume a population composition, in clusters and must be totally self-sufficient, modular, multifunctional or specialized, but always a connection terminal to a transportation grid system, above, below ground or in space. The planned population for urban cells may range from under 100 to over 10k people.

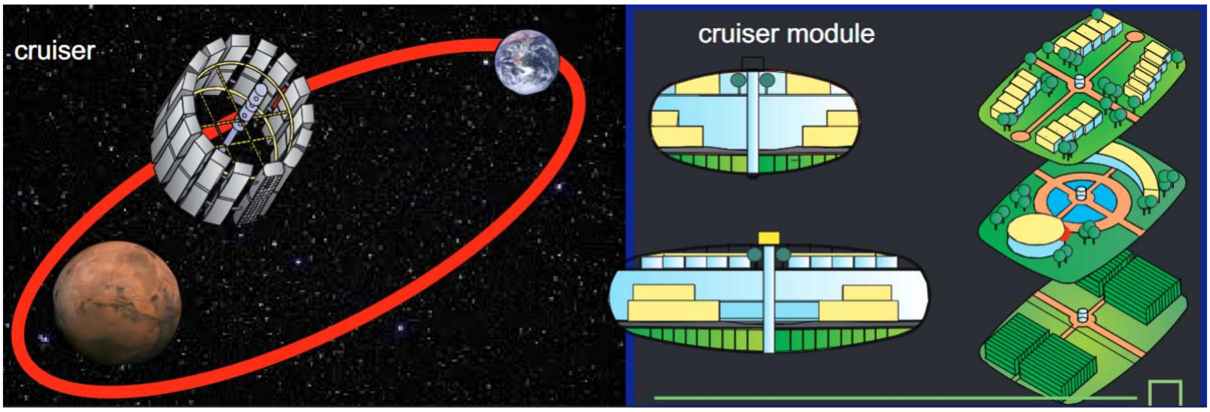

Figure-8 Cruiser and Cruiser Module

Analyzing expansion possibilities of Martian settlements, above ground the linear, concentric and the rhizomatic the latter appears to be the recommended one due to its flexibility and expansion possibilities, while the underground settlement may better be served by a concentric system reducing underground excavated areas with easy and compact expansion possibilities. The MUC would be composed of the above and underground facilities, including the vertical habitat that will connect all areas. MUC are composed of different main components with common facilities for general functioning and specialized ones for settlements with specific scopes (mining, water collection etc.) they can be summarized as follows:

- Above ground facilities (SAU or surface access units, rover workshop, laboratories, storage, agricultural, mineral processing and manufacturing buildings. and connectors
- Underground facilities, connectors and vertical habitat include offices, labs, health care, schools, services and residences, gardens and plazas. All facilities will have expansion capabilities, including vertical habitat connecting them all to a transportation termina part of the TransNars network.
- Spaceport and terminals must be considered partially underground and above ground for ease of connections with the MUC.
- Each vertical habitat must have an exclusive interior and landscape design to allow easy identification and represent a particular MUC.

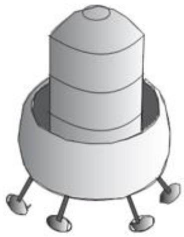

Figure-9 Shuttle

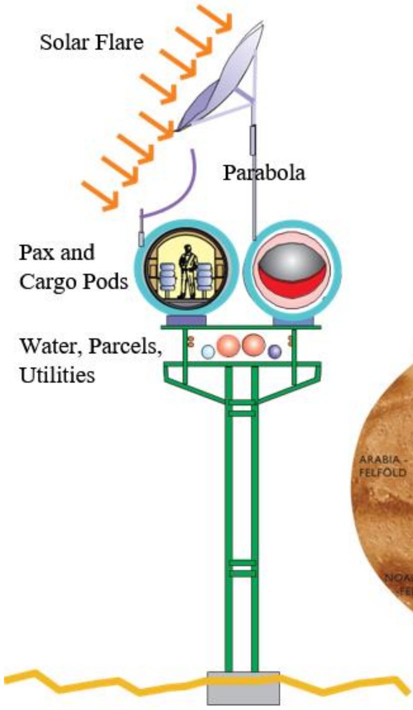

Figure-11 TransMars

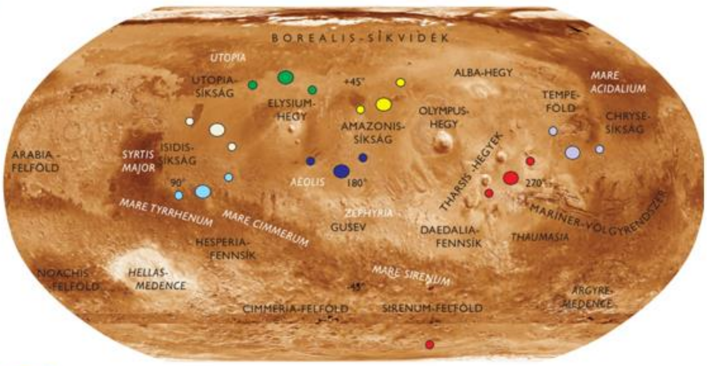

Figure-10 Settlement network

6. Base Design Concepts

Following their growth, outposts will be transformed into bases and settlements.

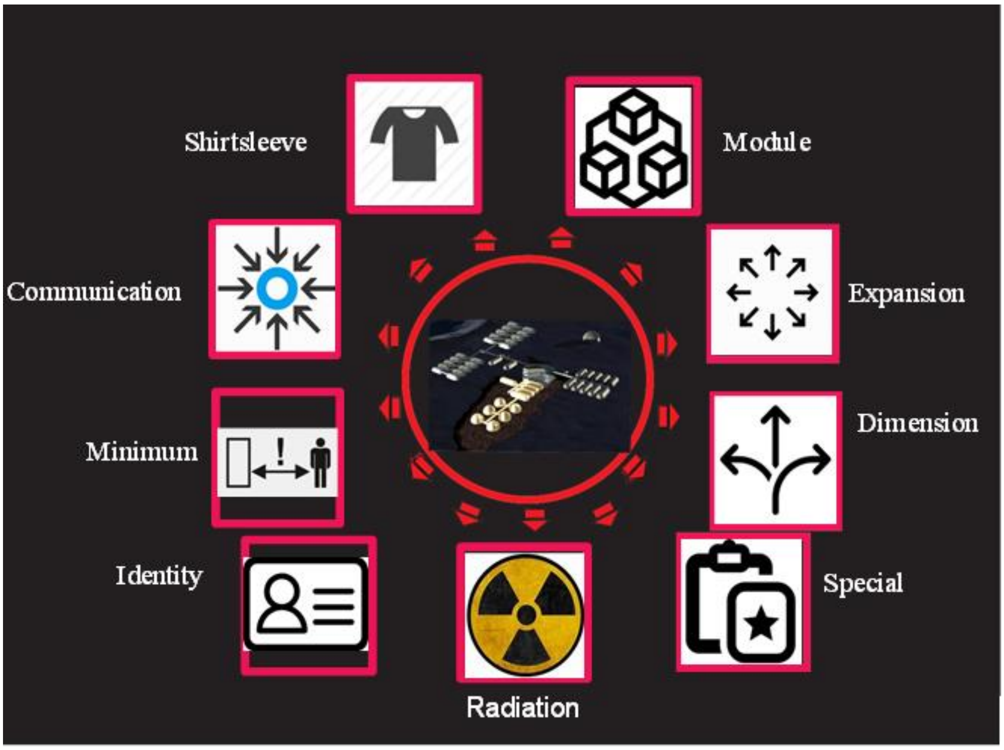

Figure-12 Basic Design Elements

7. The Basic Unit the Martian Urban Cell

The Martian Urban Cell (MUC) is a basic planning unit for Martian settlements of any size that must be functionally self-sufficient core.

The MUC must represent the basic component of Mars planning that can be isolated or in clusters and must be totally self-sufficient, modular, multifunctional or specialized, but always a connection terminal to a transportation grid system, above, below ground or in space. The planned population for urban cells may range from under 100 to over 10k people. Analyzing expansion possibilities of Martian settlements, above ground the linear, concentric and the rhizomatic the latter appear to be the recommended one due to its flexibility and expansion possibilities, while the underground settlement may better be served by a concentric system reducing underground excavated areas with easy and compact expansion possibilities. The MUC would be composed of above and underground facilities, including the vertical habitat that will connect all areas. MUC are composed of different main components with common facilities for general functioning and specialized ones for settlements with specific scopes (mining, water collection etc.) they can be summarized as follows:

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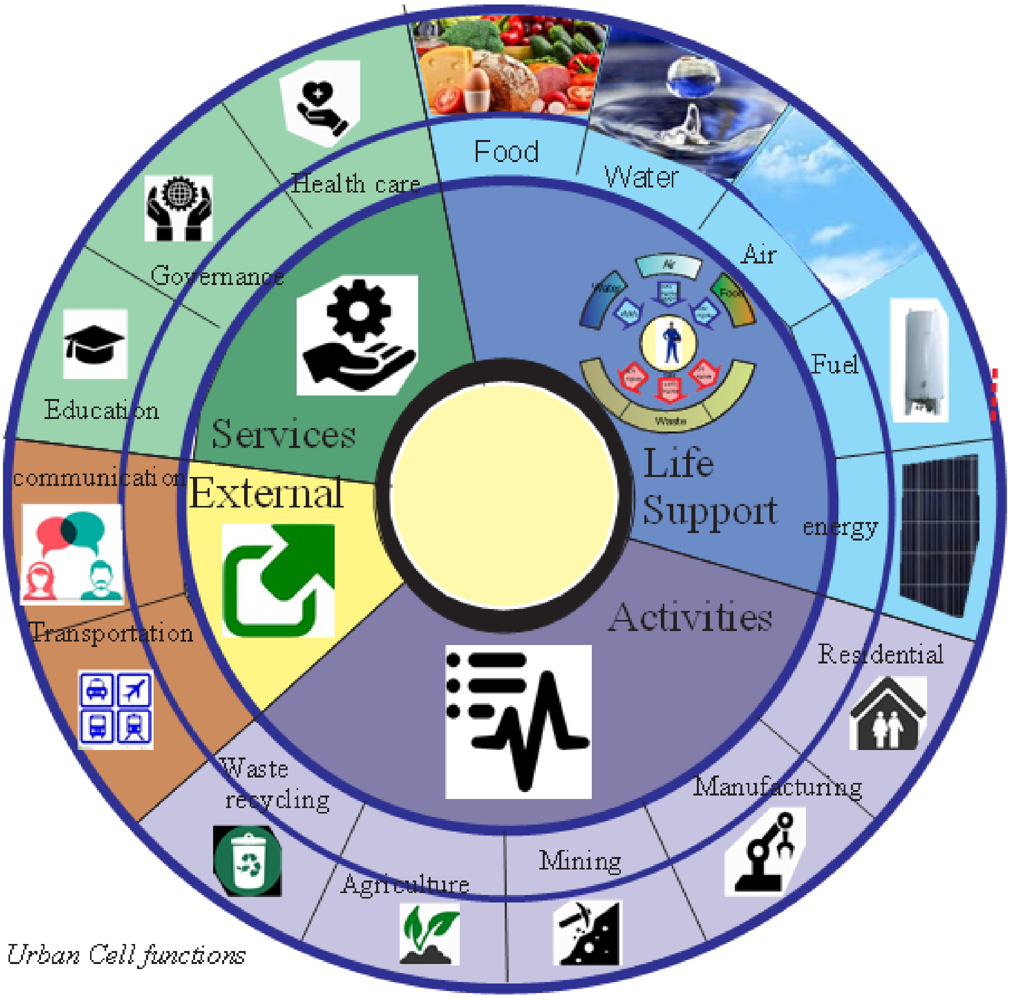

Figure-13 Martian Urban Cell Functions

8. Settlement Types

Due to the chosen scenario and the numerous activities planned there may be not a single major city but several settlements and cities, at least one for each territory governed by different organizations of various sizes. In this case the capital city population may range from small 10/40K to bigger 100/300K depending on the size of the territory and the investment, population and activities by the organization. Capital cities should be self-sufficient and equipped with all basic facilities including a spaceport to allow direct communications with our planet. Cities design will be also variable with two major common configurations, at least for the pre-terraforming age: the above (for mostly unmanned activities) and the underground (residential and manned activities) areas. Specialized cities or settlement will be created in function of their location and primary business activity.

Mining, food production, or industrial only settlements will be part of the system while an efficient transportation network must assure interchangeability between settlements for such utilities as water, power and minerals and finished products.

The outpost For a population ranging from 4 to 20 people this type is for new and specialized activities such as mining posts, water research and transformation or other remote functions requiring few human presences. It's almost entirely above ground. They can be connected to MarsNet to transport water or other minerals

The Base For a population ranging from over 20 to around 300, such settlement is composed of an underground Martian Urban Cell with all needed facilities and an above ground system of buildings and connectors to perform their activities. They are also connected by MarsNet system and in some cases can have a spaceport.

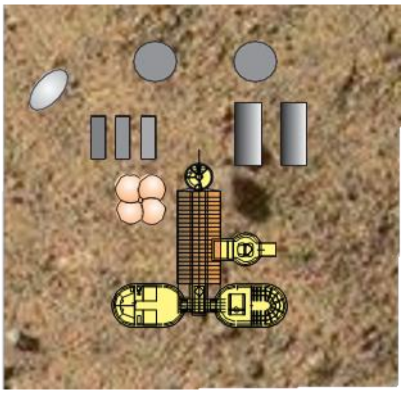

Figure -14 Single Martian Base

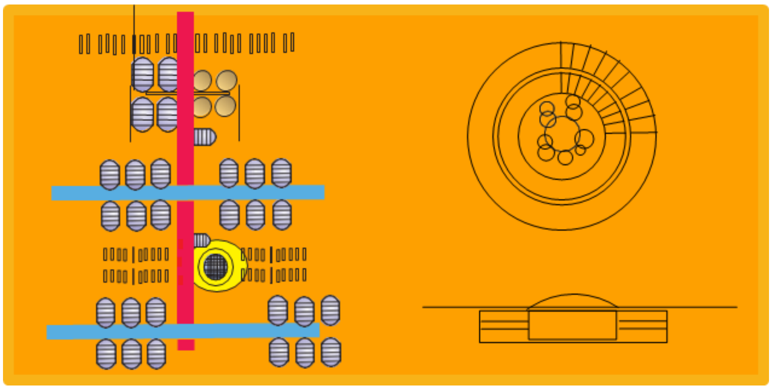

Figure-15 Base Replication

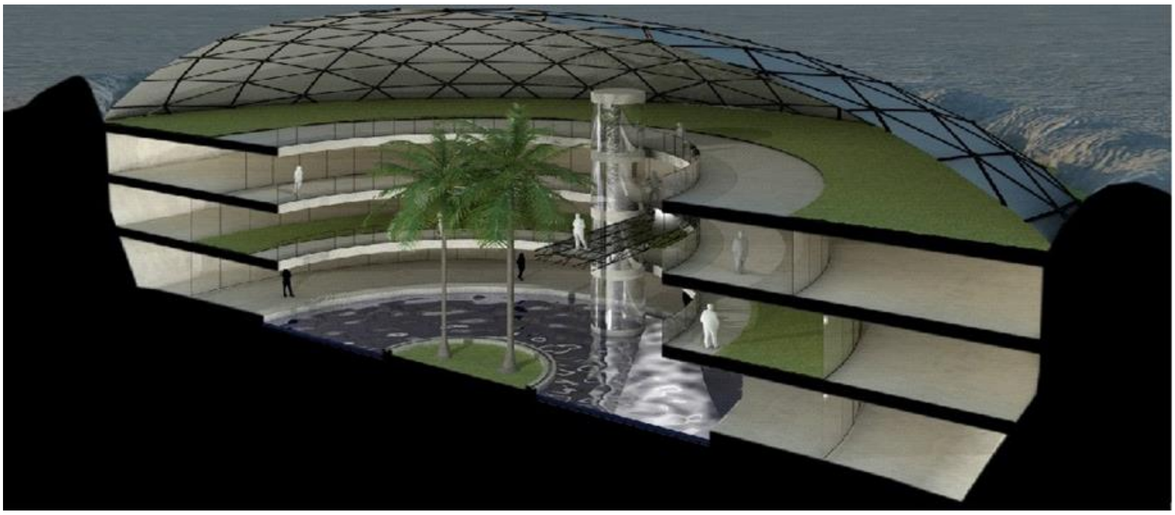

Figure-16 Vertical Habitat in Base

9. The Settlement

Utilizing the previously described components both above and underground, the MUC will become a growing settlement with a capacity of over of 1 to 5K population.

The vertical habitat would identity the settlement and would be expandable following requirements. A mall-like facility with landscaping features will identify the settlement. Total site area 250k m^2 for above ground facilities, 60k for underground.

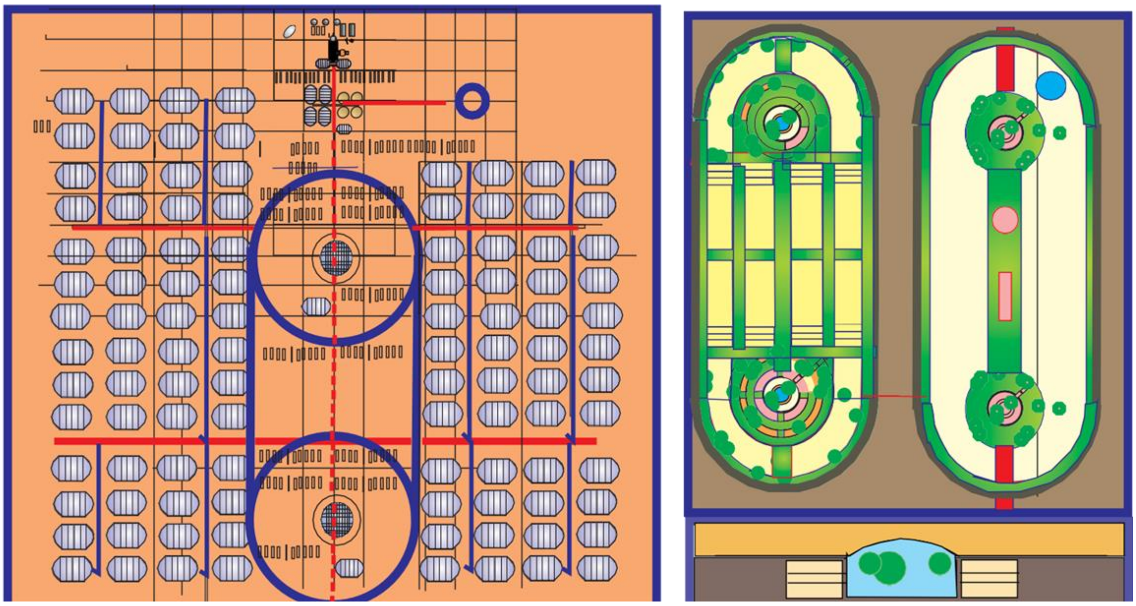

Figure-17 The Settlement

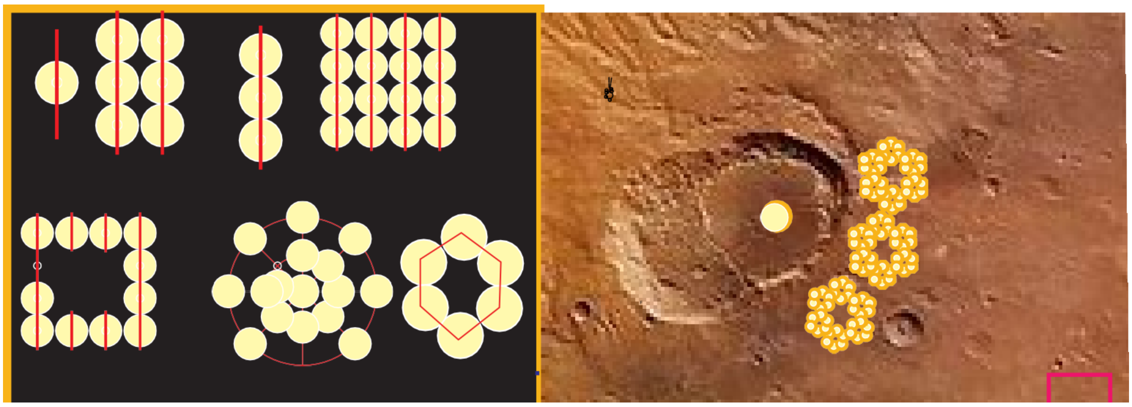

Figure-18 Expansion Possibilities

It has a planned capacity of around 50K people, the Urban Cell concept allows planned expansion up to huge multimillion population. This can be done by multiplying the urban cells following different directions, even with precise geometrical patterns or along the local topographical conditions but consisting always of a cell with TransMars terminal.

They can be adjacent or further away in accordance with local planning and requirements. While the underground part may follow a pattern, in accordance with limitations and requirements, the above ground can occupy more space based on activities growth. A fractal type of development, composed of hexagonal patterns of MUC units, connected by the TransMars system are shown.

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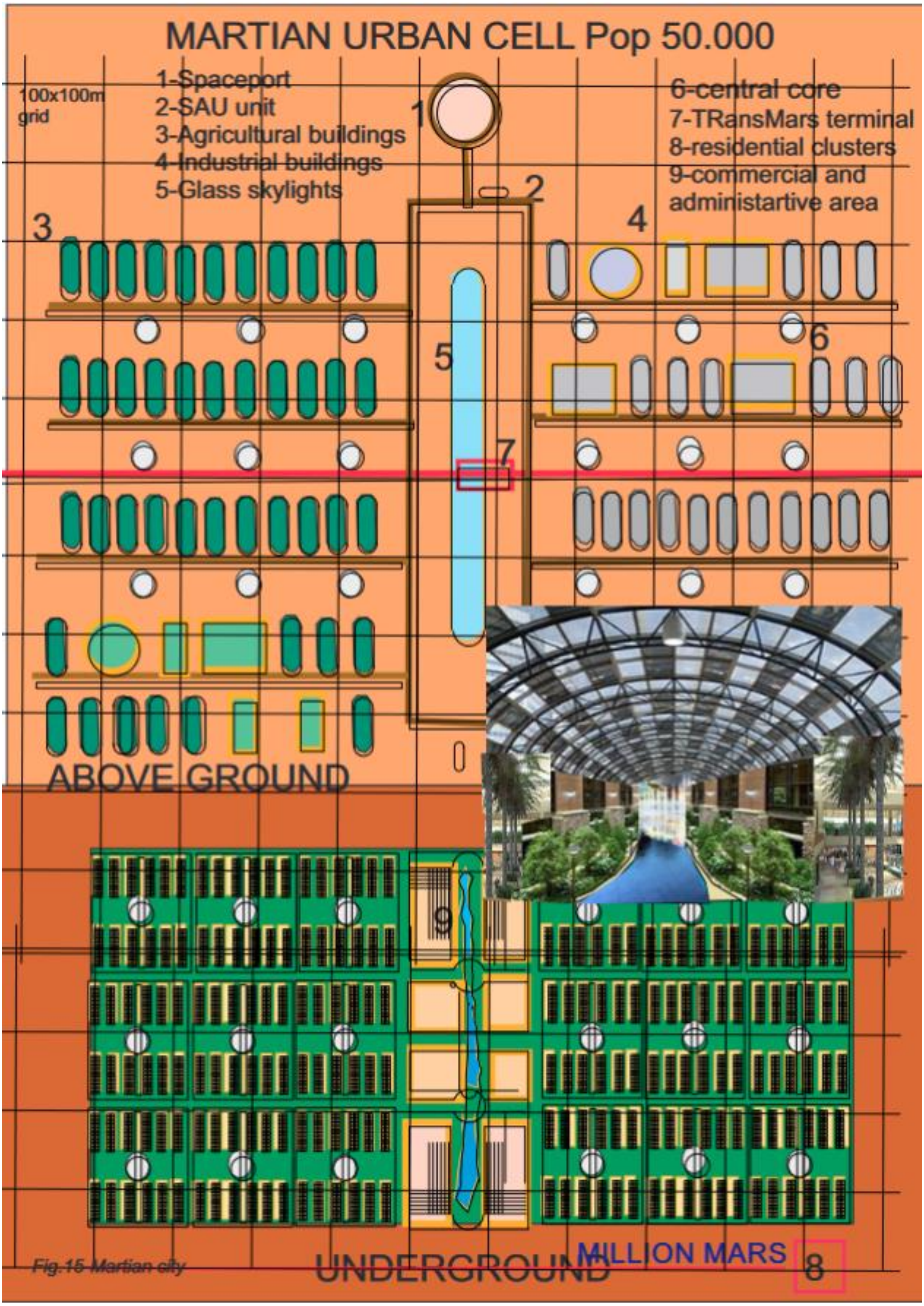


Figure-19 Underground Habitation

10. Underground Residential

The residential part of the Martian urban cell will be located underground to ensure better protection against radiation. This area will include landscape gardens and parks to improve living conditions for its population. All residential services, such as education, security, entertainment, bars, and restaurants, will be part of the residential area.

The Martian urban cell will be designed for a flexible population, utilizing modular concepts that allow for rapid adaptation to changes in population composition. The expected population distribution consists of approximately 60% single individuals under 40 (both male and female), 20% couples without children, and 20% couples with children. This ratio may change over time as singles get married and have children.

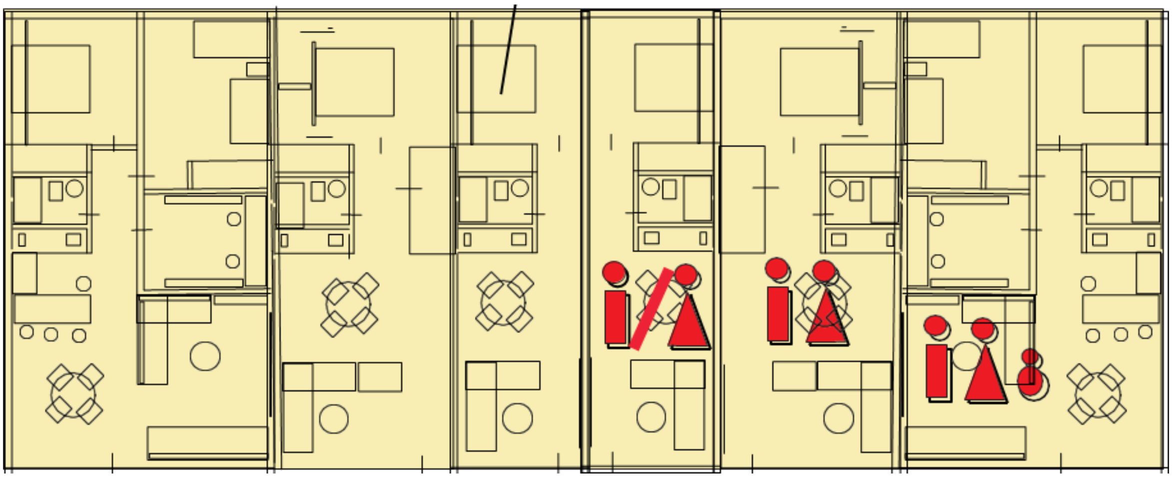


Figure-20 Plan Types

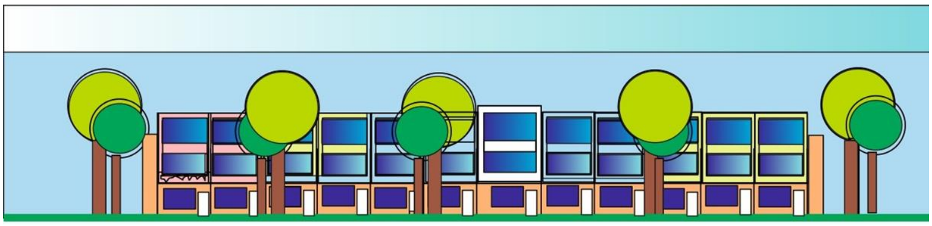


Figure-21 Elevation

11. Habitat Unit

Residential cells are designed to maximize the small area at disposal, by transforming space in accordance with its utilization. Sofa beds, upper bunks, transformable desks are some of the alternatives considered. Each unit must have the maximum privacy and sound attenuation systems, well equipped with entertainment and communication systems for the settler. They will be located underground for safety reasons, far and protected from deadly radiation. They will be distributed along a residential road that will also contain residential related facilities (nursery, schools, clubs, healthcare, playgrounds etc.).

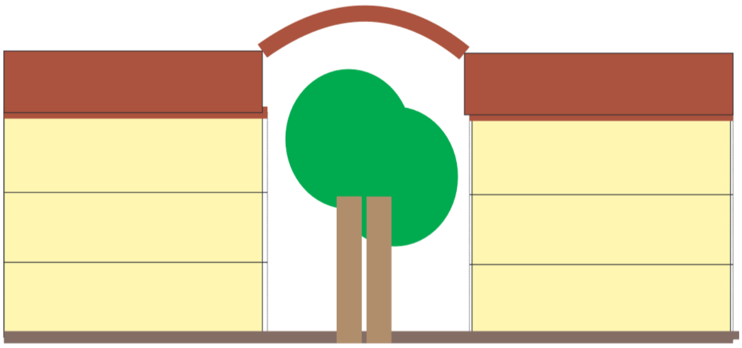
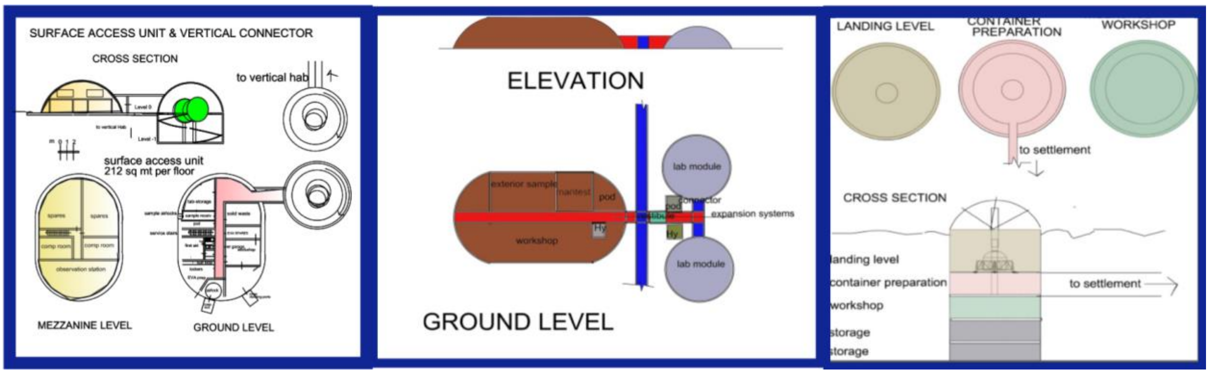


Figure-22 Cross Section

Residential services of top quality will be available to the residents. The percentage of each function performed inside and outside the basic unit will define its dimensions and equipment. We can list the external factors, which must be at walking distance from the residential units, as systems that are complementary to the residential function as visualized in this chart.

12. Main Above Ground Facilities

Main buildings and facilities needed to implement Mars vile as a self-sufficient human community, located above ground are as follows.



a) b) c)

Fig 23- a) Surface Access Unit b) Workshops and Labs c) Spaceport

Spaceport

For Phase 3 developments including supporting facilities (to be partially connected to the underground facilities) the mars spaceport will be a highly needed facility that will allow all overhauling and maintenance activities as well as passenger arrival and departure support. The protected facility will load and unload the shuttle lander, store items to be processed, be a terminal for incoming and outgoing crew. The opening system will consist of an inflatable closure, a system already in use on our planet.

Surface Access Unit (SAU)

This enclosed facility, divided into two levels, will be provided mainly to guarantee safe EVAs for the crew and vehicles as well as all supporting activities, such as rover support, storage and maintenance, material storage, first aid, airlock systems, lockers and EVA suits.

Workshop and Lab Area

This facility will contain research labs for incoming materials, to be studied and tested by the geologist for local utilization, as well as for terrestrial companies that will contract such services to the Mars ville organization. Being close to the manufacturing plants, it can also be utilized for small pilot plant tests for processing materials and manufacturing products.

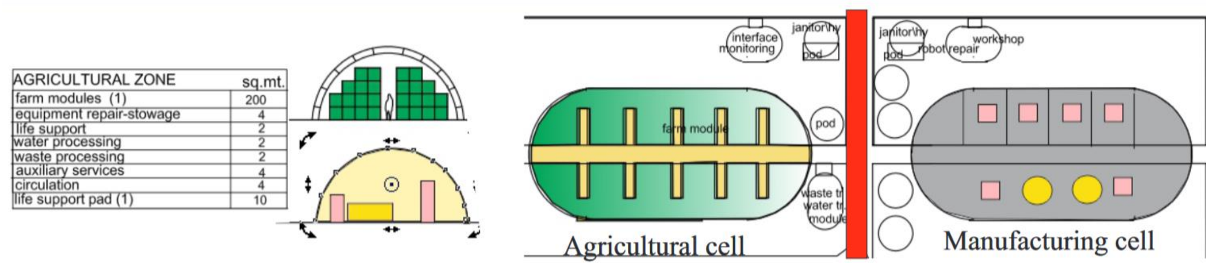


Figure-24 Production Buildings

Agricultural and Manufacturing cells

Bigger facilities, initially to be inflatables, 300sqmt each, later built through 3D printing using Martian concrete will be built to house the agricultural production needed, using where possible aeroponics techniques to save water or more conventional for corn, potatoes or fruit trees. Animal breeding is also included in the cluster named agricultural zone, mostly fish, poultry and seafood, at least initially. Similar facilities will be built for manufacturing due to the larger volume available. In later construction progress, bigger units will be considered.

Food production

Conventional high intensity, controlled environment agriculture requires 50m2 to feed one person. For a population of 1000000, we will need 50000K sq mt of agricultural area, slightly below the needed ratio but considering that 60% of that area is hydroponic agriculture its output, thirty times conventional agriculture, is more than enough to supply food for all the population.

The agricultural area will be distributed in enclosed cells located above the surface close to each settlement in the number and dimensions needed to feed its population. Some cells can be specialized for the type of crop which grows a particular species. These closed fields can be operated under controlled atmosphere, temperature and lighting conditions for fast and efficient growth of crops. Plants also clean the air and provide clean water through transpiration. Vertical 3D printed hydroponic agricultural panels will be installed in most connector walls and in residential units to increase production.

Figure-25 Agricultural Building

Nutrient	**Daily Needs**
Energy (kJ)	12950
Protein (g)	78.8
Fat (g)	128.05
Carbohydrates (g)	472.8
Phosphorus (g)	0.8
Sodium (g)	3.5
Iron (g)	0.018
Calcium (g)	0.8
Magnesium (g)	0.35
Potassium (g)	2.7

Table-1 Daily Nutrient needs per Person

Hydroponics and Aeroponics

There will be intensive utilization on Mars of the hydroponic and aeroponic system for agriculture that have several advantages

- As little as 2% water usage of soil-based methods
- Increase crop yield per square meter. It is estimated that hydroponic systems yield 23 times more than the traditional one per hectare.
- As little as 40% of the fertilizer use of soil-based methods
- A full growth system in as little as 20 days
- Up to 18 crops per year productivity or 200Kg per m2
- Half the nutrients required for soil-based systems
- Longer shelf life than other methods

For the above several agricultural buildings and all corridors will be equipped with hydroponic plantations

Local transportation

Systems not previously mentioned consist of:

- A pressurized rover vehicle for crew EVAs
- A foldable e-scooter for movements inside the urban cell

Figure-26 Vertical Farming

Figure-27 EVA Vehicle and E-Scooter

Fuel

Fuel will be one of the main manufacturing and profit-making activities on Mars. The Sabatier reaction represents a key step in reducing the cost of manned exploration of Mars through ISRU. Hydrogen is combined with CO2 from the atmosphere, with methane then stored as fuel and the water side product electrolyzed yielding oxygen to be liquefied and stored as oxidizer and hydrogen to be recycled back into the reactor. The original hydrogen could be separated from Martian sources of water. A variation of the basic Sabatier methanation reaction may be used via a mixed catalyst bed and a reverse water gas shift in a single reactor to produce methane from the raw materials available on Mars, utilizing carbon dioxide in the Martian atmosphere and water extracted from the Martian subsoil or atmosphere.

Fuel produced on Mars would be utilized on all space vehicles coming and returning to our planet as well as in future trans-mars missions, representing an important source of income.

13. Resources

The currently known resources on Mars are massive, including extensive quantities of water and carbon dioxide and therefore carbon, oxygen, hydrogen for life support, fuels, plastics and much else. The soil for its minerals and the atmosphere for its gases will be the main source of resources for the settlers. The regolith is replete with all manners of minerals. In Situ Resource Utilization (ISRU) applicable frontier technologies include robotics, machine intelligence, nanotechnology, synthetic biology, 3D printing additive manufacturing ad autonomy. Based on recent data sources, scientists think that the most abundant chemical elements in the Martian crust, besides silicon and oxygen, are iron, magnesium, aluminum, calcium and potassium. These elements are major components of the Martian minerals.

Special compact automatic equipment, partially 3D printed on mars will be developed with Martian technology as the modular mining bot shown to maximize its mining capabilities. Mineral processing systems also utilizing Martian created technology, compact, self-sufficient fully automatic, will be part of the manufacturing ecosystem that will include compact robot operated fabrication systems to utilize and manufacture with processed local minerals.

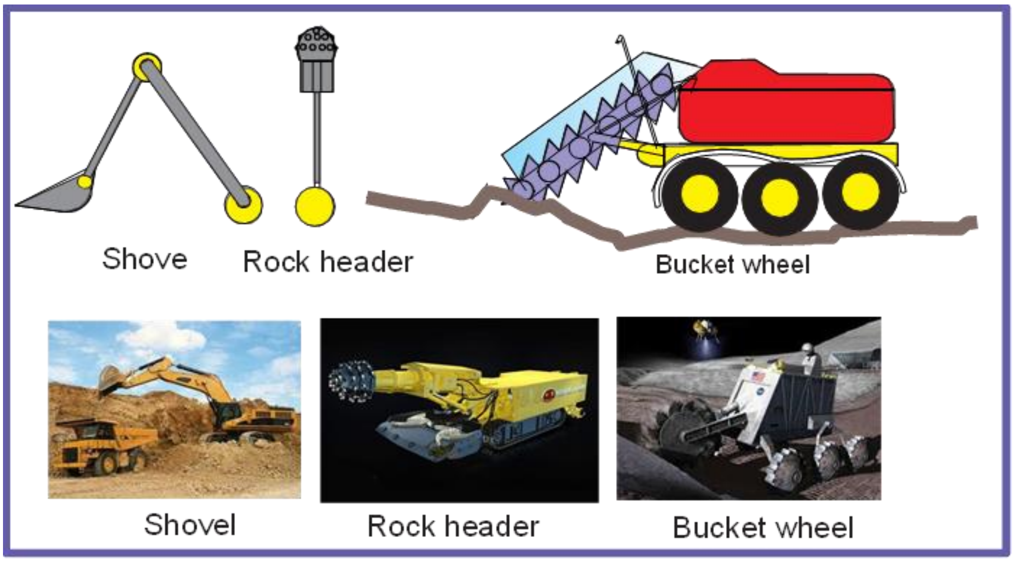


Figure-28 Mining Equipment

14. Construction Industry

The most important technology, after life support systems, for a successful Martian development, is building technology. Such technology, including new components and systems, must enable the settlers to build the volumes needed by utilizing local resources without the need to bring anything from earth, except special equipment. As an example, a special type of bricks can be 3d printed on mars and utilized for many functions. Let’s analyze in the chart most common construction components, needed materials and availability on Mars.

Martian construction systems will make deep use of 3D printing techniques.

Martian concrete, obtained from regolith, will be used for heavy construction like external walls, block manufacturing vault construction. A more sophisticated system, utilizing PET like material obtained from the atmosphere will be manufactured like assembly containers, designed with all utilities and furniture included, filled with regolith for radiation protection and water in internal walls.

COMPONENTS	Materials	Minerals	Equipment	Origin
foundations	concrete, structural steel	cement + iron	mixer, furnace	Mars
slab on grade	concrete, structural steel	cement + iron	mixer, furnace	Mars
vertical structure	concrete, structural steel	cement + iron	mixer, furnace	Mars
floor slabs	concrete, structural steel	cement + iron	mixer, furnace, mould	Mars
external walls	blocks	clay +	mould, oven	Mars
internal walls	bricks, metal, glass	clay +	oven, profile, oven	Mars
windows	metal, glass	iron, silica	oven	Mars
doors	sheet metal	iron	laminate	Mars
floors	ceramic	clay +	mould, oven	Mars
electrical				Earth
sanitary				Earth
HVAC				Earth

Table-2

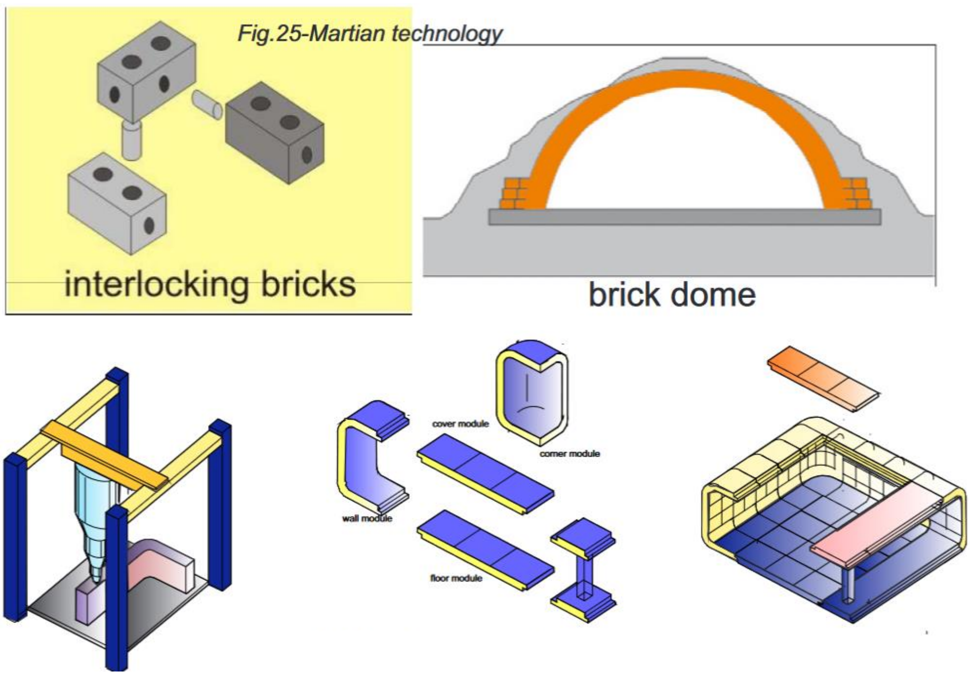


Figure-29 3D Printing Technology

15. Power Generation

There will be two sources of energy that will be used. When the settlement first begins development, it will mainly rely on solar power. This is because solar panels are easy to install quickly and can be done autonomously. Furthermore, the solar powered equipment can produce electricity without any type of mechanical or power conversion. However, when more mining facilities and humans begin to populate the Martian surface more energy will need to be produced, more than the solar panels will be able to handle. At this point nuclear plants will be built to meet the new needs. Equipment used to build the energy production facility can be reassigned to commence mining or any other necessary tasks when this facility has been completed. As an alternative we may consider solar satellites in Martian synchronous orbit that will supply power by microwave to Martian rectennas that will supply such power to the settlement.

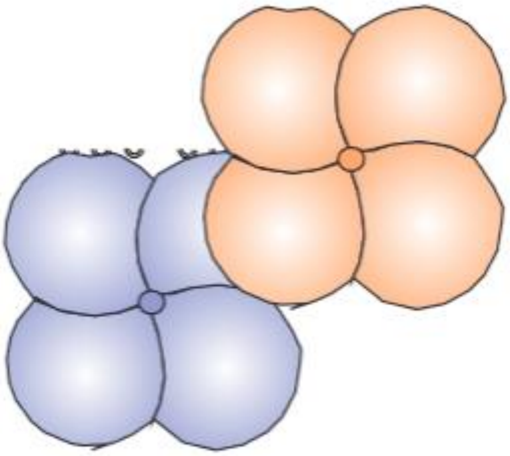


Figure-30 Solar Flower

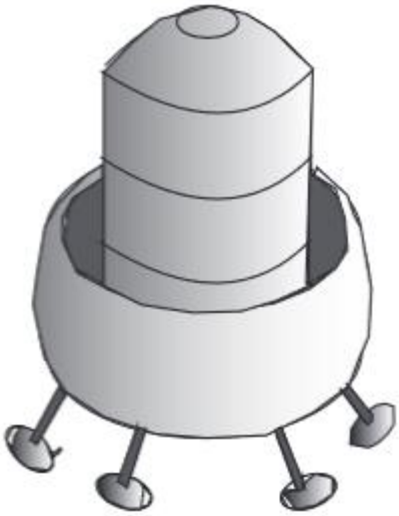


Figure-31 Shuttle Vehicle

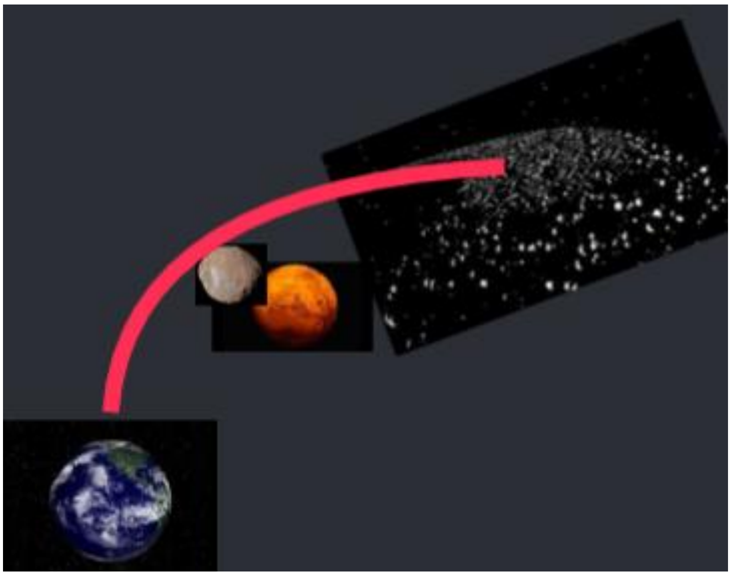


Figure-32 TransMars Missions

16. Phobos

Due to its location, orbiting a few kilometers from Mars, Phobos could be a perfect natural waystation for an Earth- Mars transportation system. A base on Phobos would allow early and secure access to incoming cyclists directed to our planet as well as incoming passengers to Mars.

It could also be utilized as a refuel station for cyclists and also for TransMars missions since it could supply not only Mars made fuel but also water, food and any other supplies and products made on Mars and can function, if needed as a logistic station.

For that purpose, a base on Phobos was created complementing the system on Mars. Shuttle vehicles, as shown, would carry cargo and passengers back and forth Mars and Phobos

17. Health Care

Space settlements must be subject to a severe and tight health care system, focused on people, with the following principles, considering that being an enclosed society any disease could spread immediately between

the population and its instant detection and elimination are necessary.

- Disease free society
- Free and immediate health assistance for everybody
- Computerized mapping and database for every person
- Immediate intervention to prevent any spreading of disease
- Population monitored constantly for intervention in real time when an alteration is detected
- Artificial wombs for pregnancies avoiding risks to women
- Gene engineering intervention to eliminate genetic diseases and allow perfect physical body conditions from pregnancy/

Strategy for Disease Free Society:

Interventions in real time as soon as any alteration in body cells are monitored by an injected nanochip system to avoid spreading of any potential disease due to the alteration. The procedure would be the following as visualized in the flow diagram for prevention and treatment situations utilizing the following equipment and digital system: Each person will be provided with an injected nanochip that will constantly monitor main conditions at cellular level. Any alteration will be monitored in real time and alarm the health center of the patient that would recall him /her and treat immediately before further spreading. Telemedicine systems will be widely used.

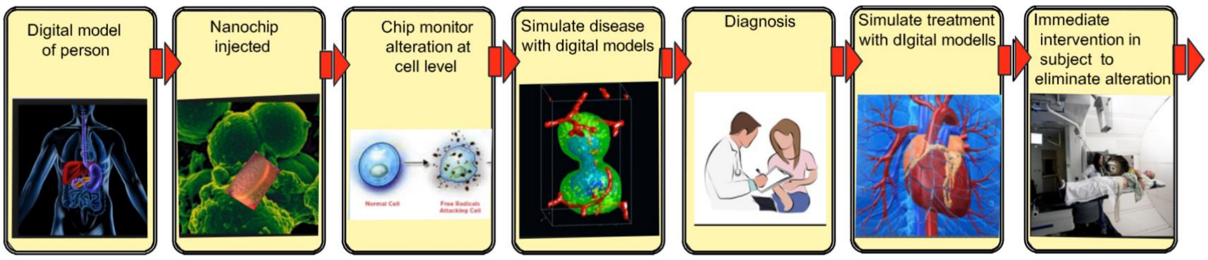


Figure-33 Health Care Flow Diagram

18. Education

On Mars the educational system must be updated to the expected technological level and local conditions. It must be entirely revised compared to the existing terrestrial on including teamwork and remote learning with utilization of new technologies, new subjects and new approach to learning. Education will start from the first years of life and be permanent, compulsory and free for everybody. Education will be based on Exponential Creativity concepts and methodology including collective intelligence, developing skills and performing activities, dynamic multimedia textbooks, games, projects, brainstorming and competitions reducing traditional learning time by an order of magnitude.

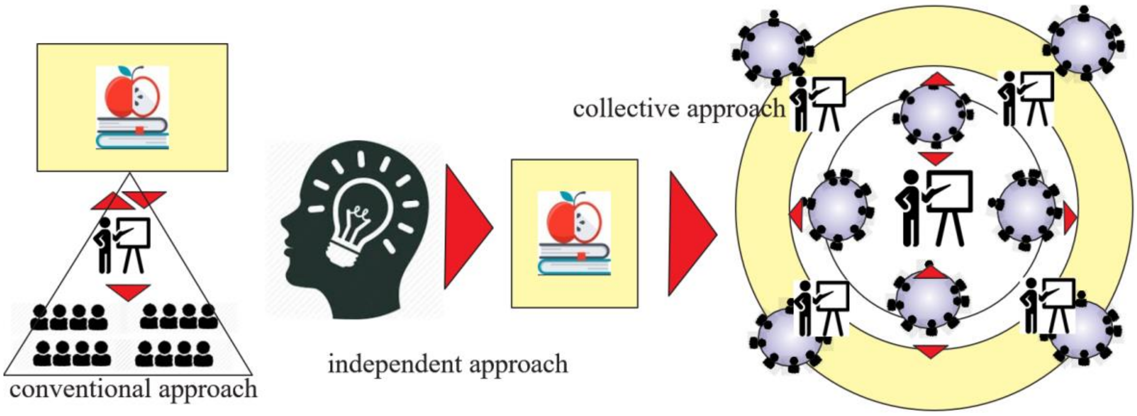


Figure -34 Educational Approach

While everybody will have unlimited access to all knowledge through the web, the educational system must teach its students how to manage such power. For that reason, the preparation will be mostly based on how to concepts than on simply cognitive subjects substituting the traditional hierarchical pyramid structure with a new circular and democratic one.

19. Facilities

Educational facilities must reflect the new requirements and behavioral advances of the learning system. For accessibility nursery, kindergarten and primary school will be located in proximity to residential areas and composed of indoor, outdoor and learn at home areas and equipment. Most advanced schools for other age groups, including permanent learning, will be distributed in the community areas of the cities. Utilizing web conferencing virtual classrooms can be organized to include participation of7terrestrial students enhancing and improving their learning experience.

20. Governance

Managing a Martian colony in a hostile environment and at a remote distance from earth, based on an advanced Constitution we will need a particular system of governance that will not allow random decisions without verifications possibilities. For that reason, specific management programs, one for each system, health care, economy, finance, etc.) will be prepared and implemented. Such programs will collect all data in real time for each item, shown in a visual dashboard with trends and potential risks monitored by a management information system that will point out any deflection from optimized previsions and indicate which actions must be taken to correct the situation. The entire operation will be monitored by an AI of the highest capabilities. Such a system will be applied to the general colony governance allowing its representatives to have an at the glance situation.

While the system will be composed of the classical and separated three powers (judicial, legislative and executive), the main condition will be a totally independent nation with its specific constitution, laws and regulations that consider the particular situation. Together, the Martian settlements system may form a federation to deal with common problems and challenges, it is probable that the financing entity would retain some sort of control on the settlement. For efficient purposes, considering the particular conditions of the settlements, we must avoid political effects as on our planet (corruption, nepotism, mismanagement etc.) we are proposing a system run by AI of highest capability, that given the goals by the human counterpart will supply alternatives and recommendations on actions to be taken avoiding the possibility of human errors. Such recommendations must be approved by the human board in order to be implemented.

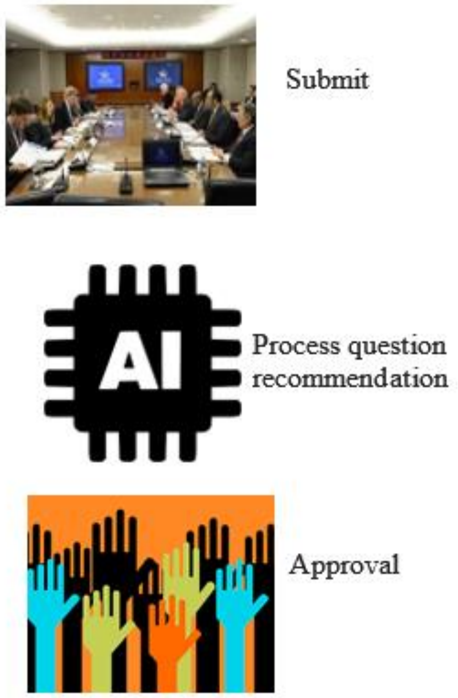


Figure-35 Decision Process

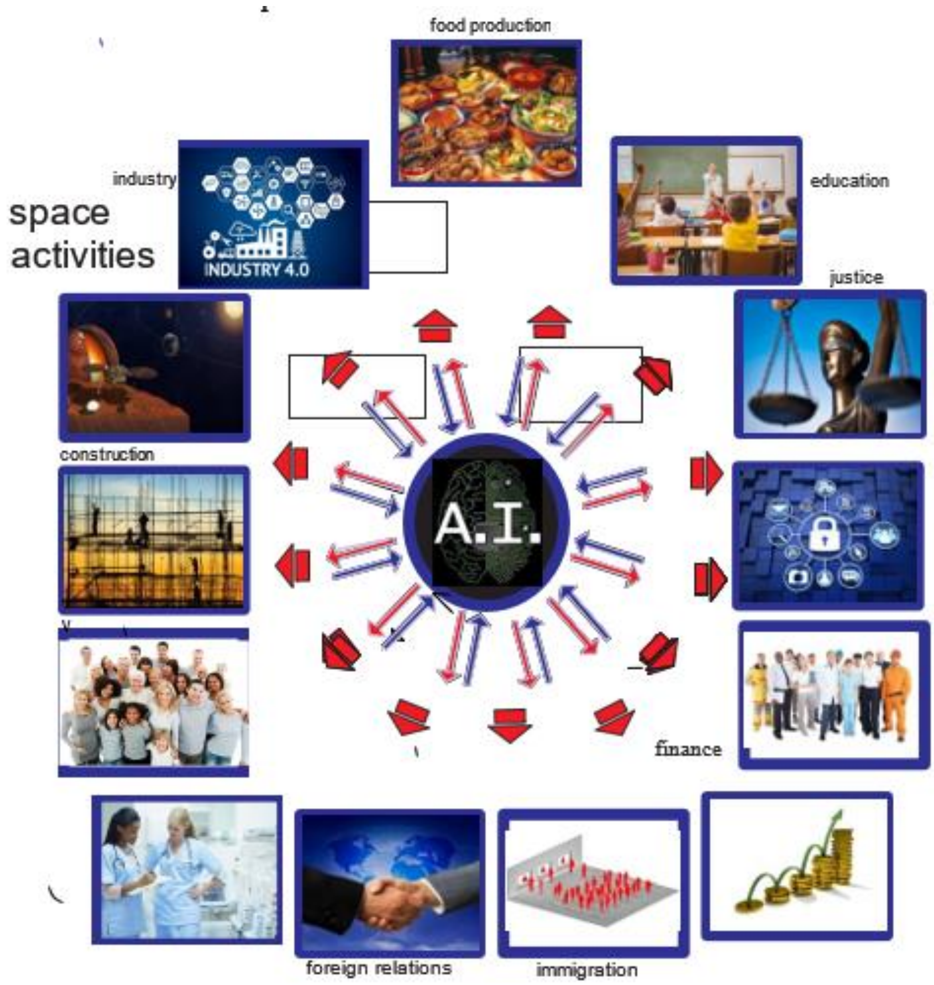


Figure-36 Governance System

21. Economic System Evolution

The chart shows the evolution of the main activities of a Martian economic system. They range from the initial prevalence of life support systems to allow basic survival, to more sophisticated and large-scale food production and processing, mineral and gas processing to obtain raw materials for manufacturing using 3D printers on massive scale for most products of common usage such as housing, robots and rover manufacturing. The economic system's existence and growth as an independent and self-sufficient entity is the main goal and the economic system must reproduce the terrestrial one especially in the post-terraforming age. Imports from our planet must be minimized in the long run and limited to pharmaceutical or sophisticated electronics.

An all-new Martian technology will be developed to sustain the economy, while common products will be adapted, even improved, to the new technology and materials. The new technology will have minor implications with the terrestrial one and exporting materials as well since on Earth most will be available, unless a new, exclusive or particular one may be found worth paying considering the huge transportation costs. For that reason, the Martian economic system must be based on a totally self-sufficient one whose growth will be fueled by the arrival of new settlers and business activities on the planet. Supplying logistic services, shelter, transportation, food, fuel, water and all needed services will be the main activities. To encourage new settlers a homesteading system will be enacted, donating land and financial support to new settlers while a specific claims system to encourage arrival of new settlers will be enacted. In the chart we are showing some of the main activities of the colony.

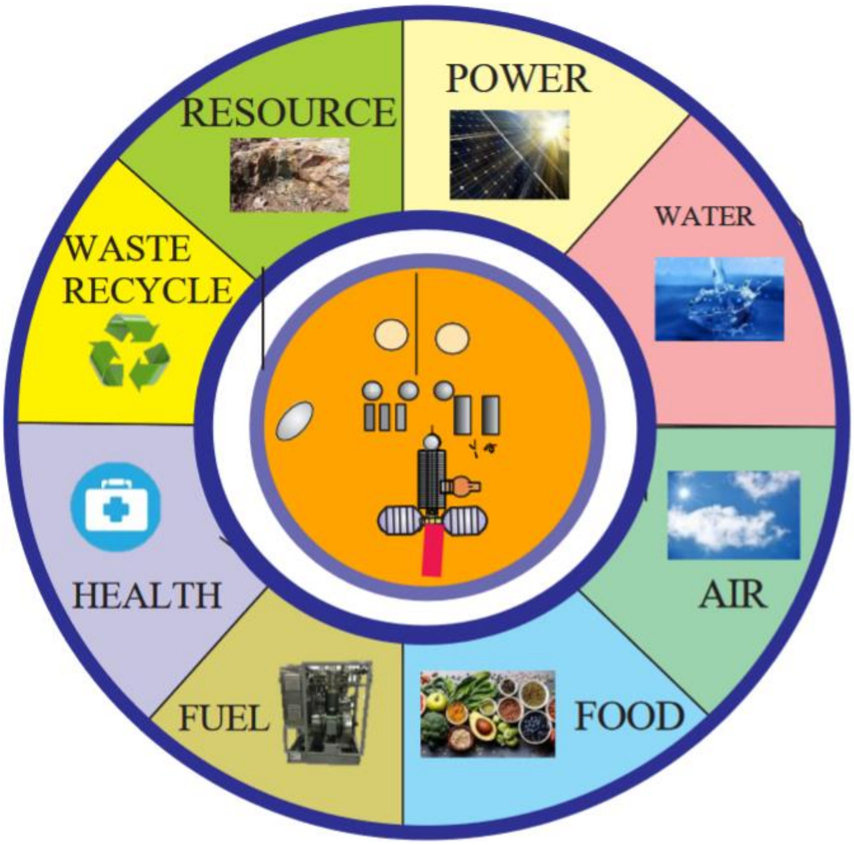


Figure -37 Initial System

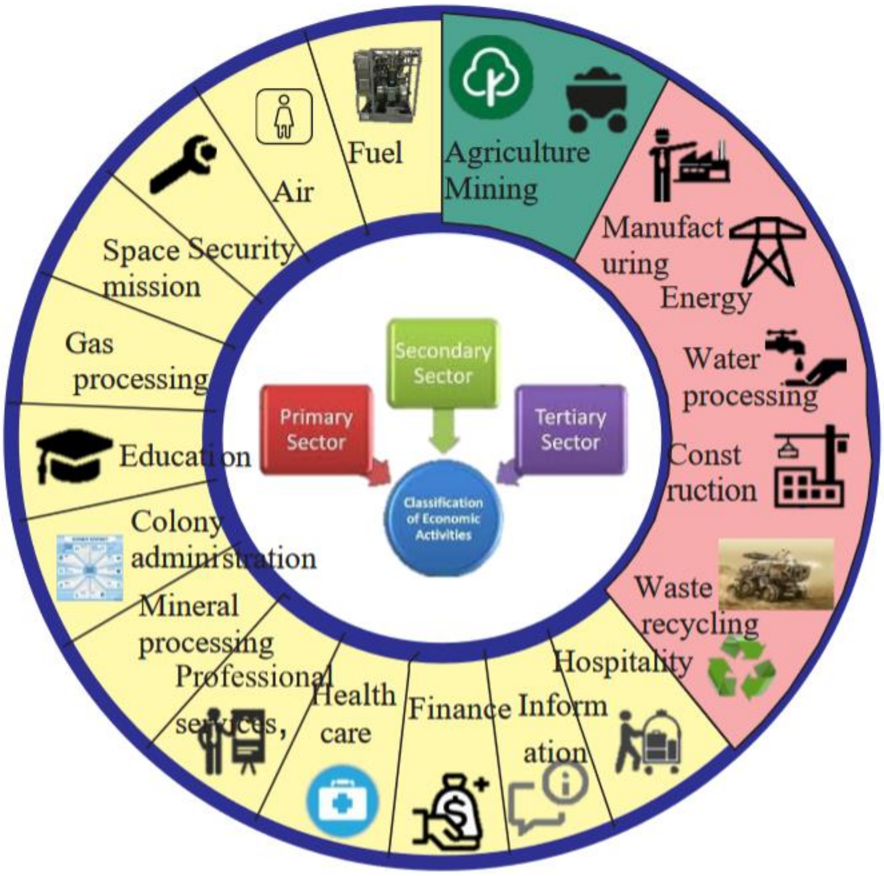


Figure-38 Operational System

22. Terraforming the Designed Planey

Having established that Terraforming is the main condition for the complete and fast development of a Martian economy and a Martian society, following the recent pandemia on our planet, the need for a second home for humanity is becoming more obvious. A Terraformed Mars is the only possible candidate in the solar system and such an opportunity must be considered. A population of one million people on a hostile and barren planet is not convenient while a much bigger in a friendly planet will be welcomed and will guarantee a steady development of its economy and its society. For that reason, but not only, the terraforming of Mars is also a must.

While such a process will take decades and enormous amounts of money, we must apply what we learned on our planet over centuries and avoid the mistakes that were made. The planet must be pollution free, with proper technology disease free as well, and must guarantee environmental and social optimal conditions. Its physical shape must not be conditioned by random changes in the territory but, at least in the settled parts, it must be designed to optimize its utilization, physical looks and allow a symbiotic relationship between the natural and the artificial ecosystems. Green areas, water bodies, highlands must be designed for beauty as well as functionality and maximize the utilization of land and its resources while respecting it.

A symbiotic relationship should allow the physical separation but functional integration between the natural and artificial ecosystems. It will be the main goal of a designed planet Mars. maximizing its natural features while allowing a correct intervention of artificial facilities and megastructures. There are many different proposals for Martian terraforming, based on different chemical processes that will change its atmosphere, climate and temperature conditioned by the system selected at planetary level that we will not discuss nor evaluate in this paper. But we must not forget another danger, radiation. Future technology should be developed to activate a Van Allen type of antiradiation belt to allow a safe life on the Terraformed Mars.

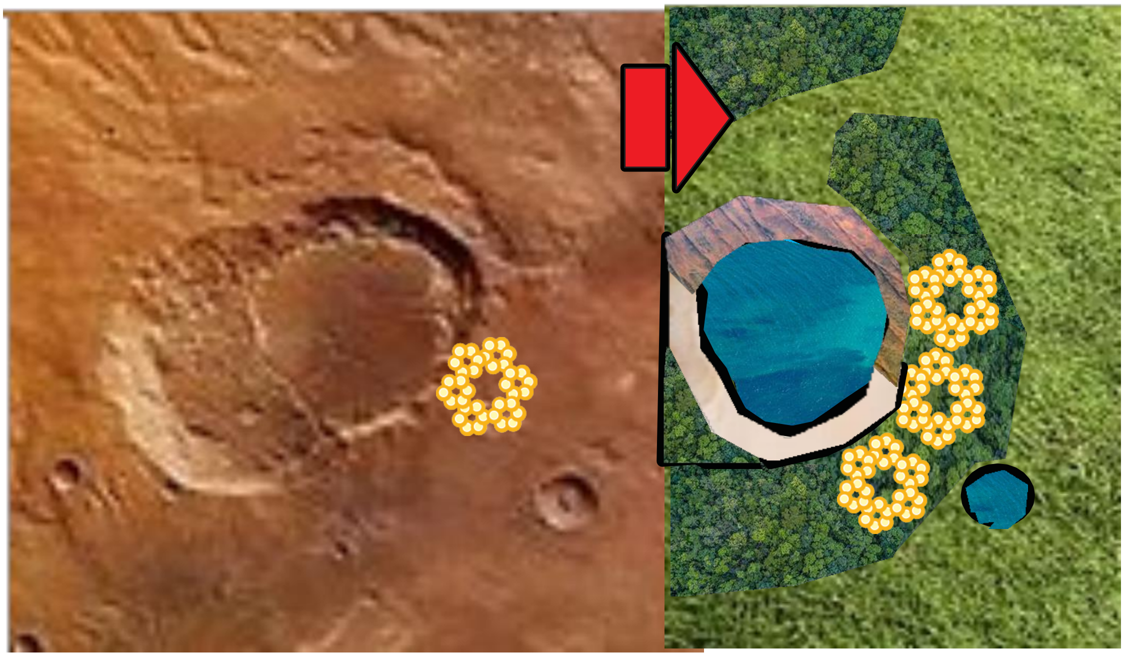


Figure-39 Terraformed City

Here we want to emphasize the enormous push that terraforming mars will have on the general economy and the public imagination. The possibility of contributing to such a process and starting a new life on a different planet will represent a new frontier for humanity and a potential goal for entire generations. A Martian urban cell designed with the symbiosis concept, while multiplying the natural areas and the land possibilities is shown.

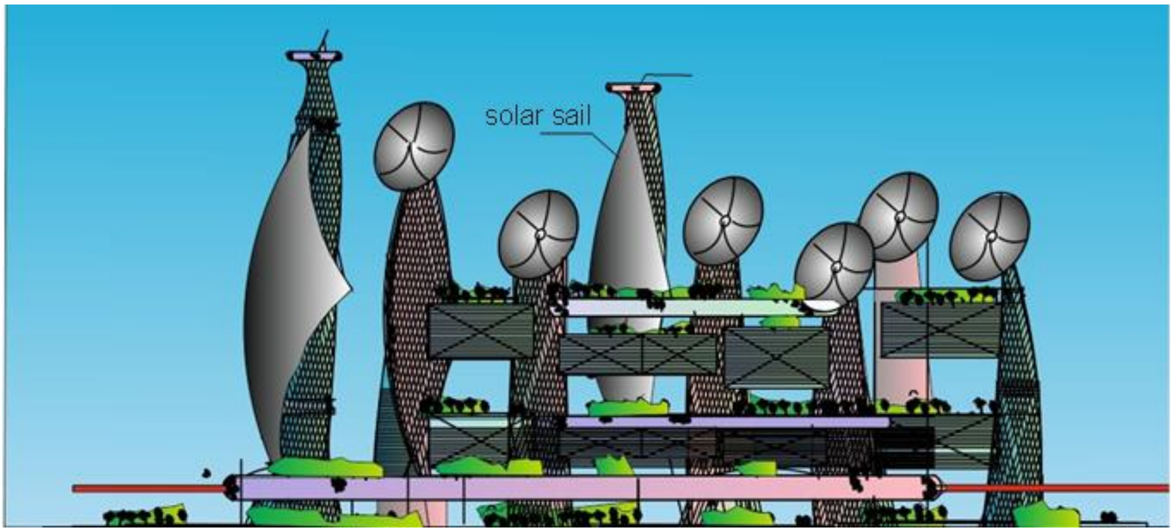


Figure-40 Terraformed Cityscape

23. Conclusion

Humanity has the possibility to create an entire new world leveraging on the experiences, positive and negatives, from its own history. This could be the biggest opportunity for humankind. Is up to us, our leaders and our society to realize such fact without letting ourselves be misguided by ideologies, nationalities, religions and more. Technological improvements will follow, travel time will be drastically reduced, and an entire new world will be available. The public must be educated to understand this opportunity and look forward to implementing it.

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25. Conflict of Interest

The author declares no competing conflict of interest.

26. Funding

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