The Republic City State of Tharsis: A Habitat of One Million People on Mars

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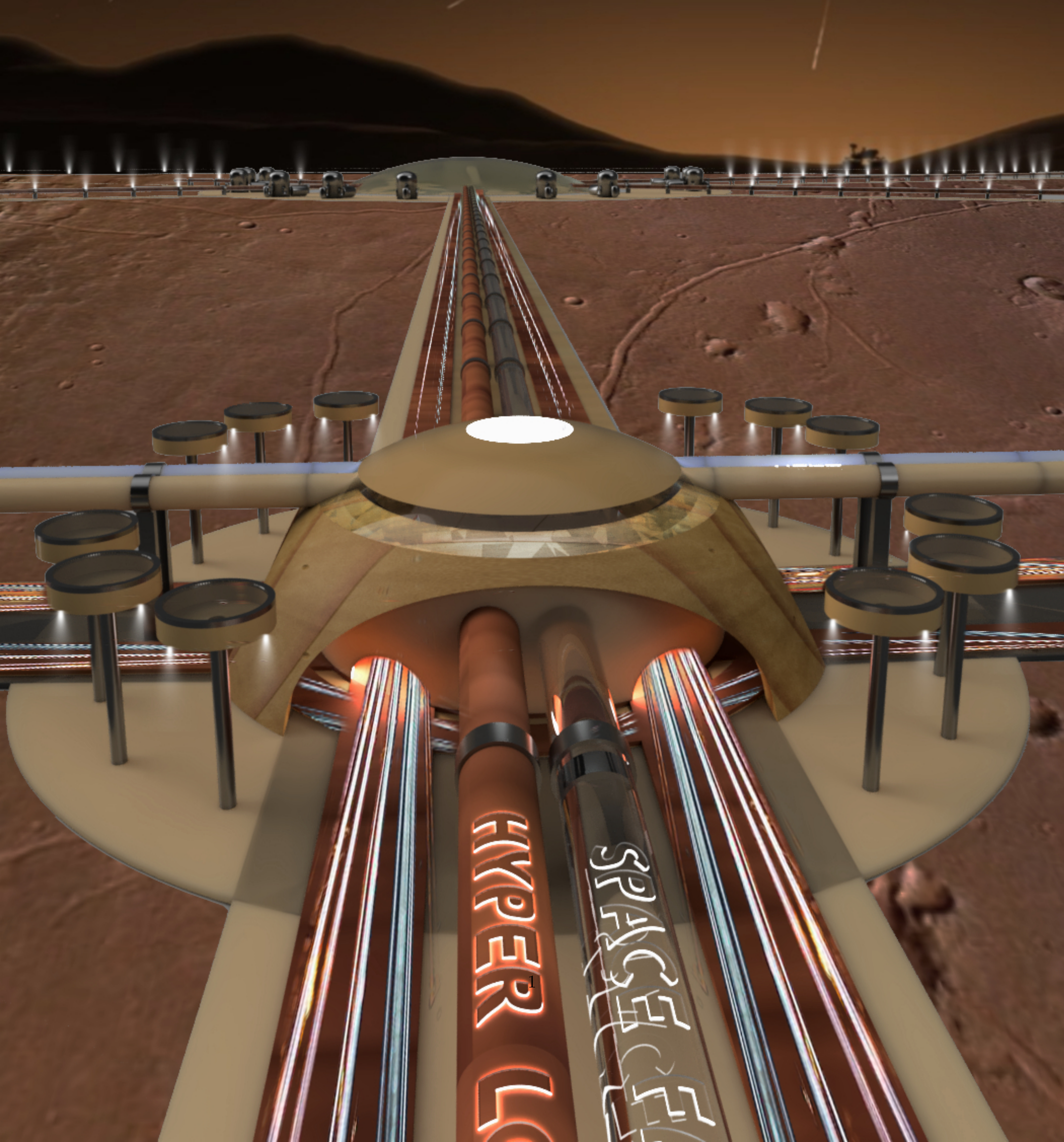

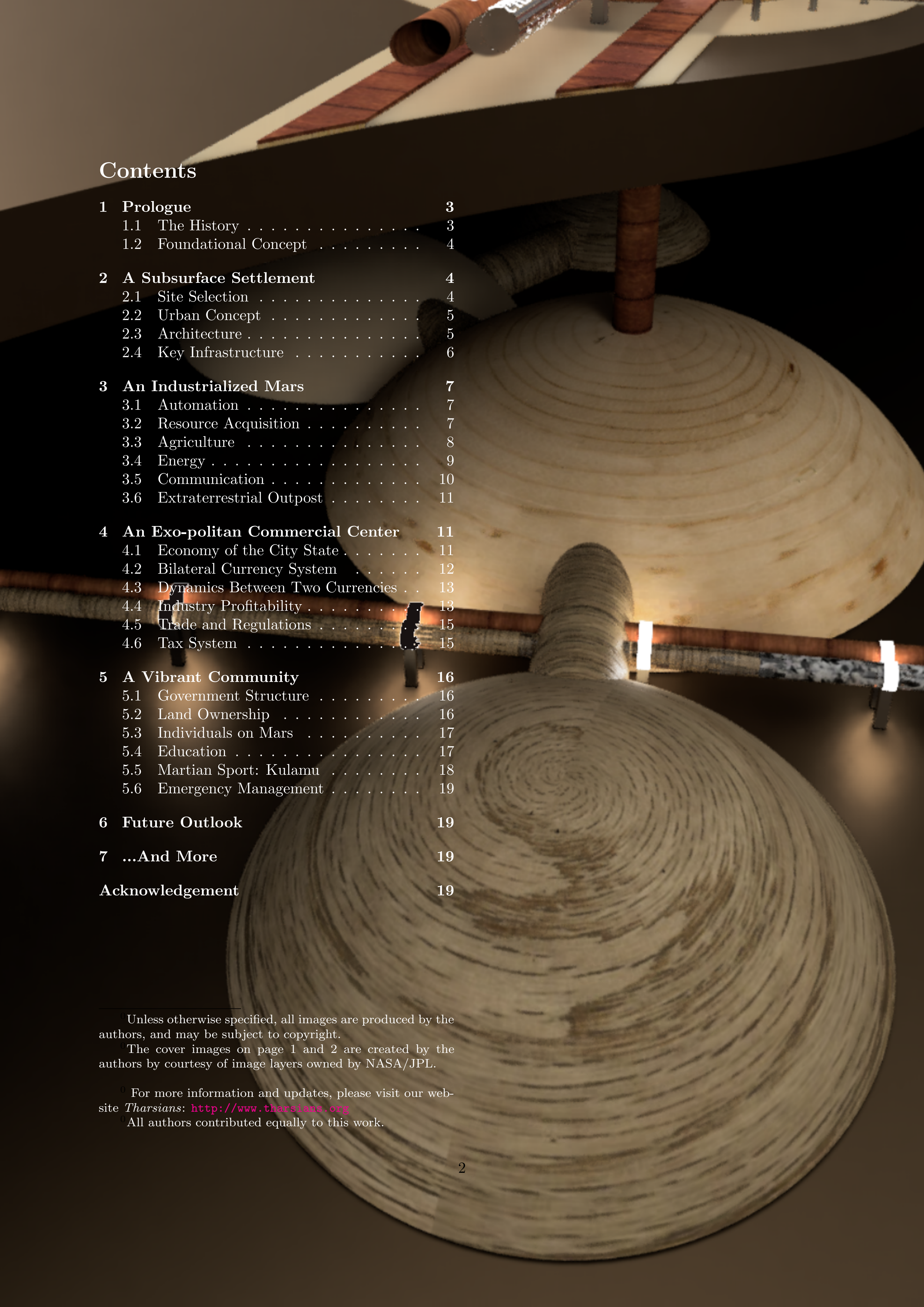

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1 Prologue

1.1 The History

On the day May 30th, 2020, for the first time a private company successfully accomplished a human spaceflight mission with a recoverable launch vehicle. Humanity saw new hopes to its grand vision of becoming a multiplanetary species. In 2035, a global treaty was signed by hundreds of countries, and humanity aimed high: to build a city state of one million on Mars.

The region of Tharsis Montes was selected to be the destination of the pioneers and the cradle of the first human settlement on Mars. The endeavor took centurial efforts to come to fruition. The colony, later deemed "The Republic City State of Tharsis," has gone through four fundamental development stages so far: Corporatization, Sectionalization, Centralization and Decentralization.

Corporatization was the establishment of a society structured as a corporation in the beginning stage of the development. Funded by both private and public investments, the Tharsian Corporation was established in 2038, directed by the Mars Committee. Within the next 7 years, the committee selected, trained and transported 2,105 scientists, engineers, technicians and city planners, and 42 autonomous robotic devices to planet Mars. By 2070, these personnel completed the environmental modification of lava tubes under Arsia Mons, built underground settlements and the prototype of the Energy System, and paved the way for businesses to enter Mars.

Sectionalization started when the basic structure of the City State had been established. The City State was divided into autonomous districts with local governments and a central government to better cope with the individual needs of every region. Prestigious universities around the world lined up to open research centers on Mars. Real estate market on Mars bloomed. Business opportunities were at the height that was never expected. The Committee sold licenses for the entrances to Mars for personnel in private enterprises, offered loans and accelerator programs for startup companies, and guaranteed free entrance licenses for talented individuals and teams with great potential. The State government and district governments became well-funded through the sale of these licenses and tax collection. Many companies and individuals maintained steady growing profits renting their real estate properties to small and medium businesses. With rapid commercialization, by 2085, most of the infrastructures on Mars had been developed and there were approximately 500,000 people living in the City State.

The Centralization process, which gave the State Government the right to collect federal taxes, was initiated to resolve the remaining difficulties in constructing a self-sustainable Mars society. One such difficulty was that crucial services like productions of food, water and oxygen are difficult to privatize at low market prices. Also, the high interplanetary toll fee from Mars to Earth made it extremely difficult for preliminary businesses that exported goods to Earth to survive, and forced many companies to leave Mars. Policies deployed to address those issues had been successful. By 2085, the City State had become a fully functioning colony of roughly 800,000 people. In the same year, city state "The Republic City State of Tharsis" was officially established, and all districts ratified the common constitution of the City State. The central government and district governments certified the state anthem "Life on Mars", inspired by the song under the same title by David Bowie written in August, 1971.

The Decentralization is the most recent stage, initiated in 2100 and remains to present. The main objective of decentralization is to provide a free market, while ensuring the survivability of new businesses on Mars. This process is aided by industrial developments on Mars – especially the research on more efficient ways to manufacture essential products and the engineering of new propulsion methods to lower the interplanetary transportation costs. Meanwhile,

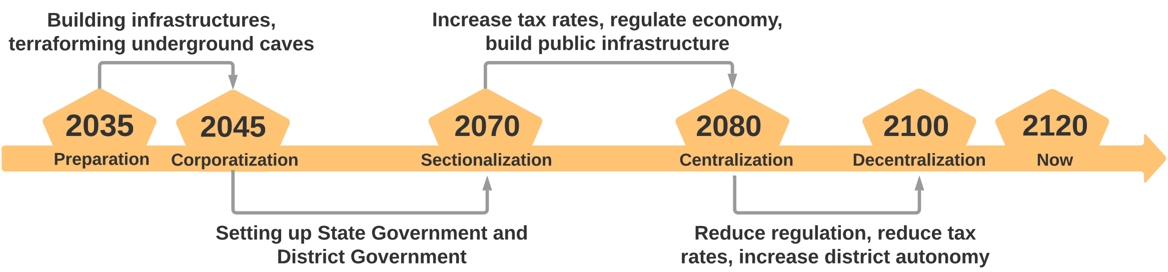


Figure 1: Development Timeline.

Figure 2: The City State Flag.

the central government gradually lifted tariffs and cut taxes. Eventually, by 2120, humans have finally reached the milestone of 1,000,000 people on Mars – the goal set by far-sighted pioneers a century ago.

Up to here, humanity has learned the potential of joining hands. Now the ambitious Martians have passed the initial stages of scarcity, and capital is flowing towards research and technology that enable Martian settlers to further terraform Mars. It has been a vital stepping stone for humanity to set out further into the unknown void of the universe.

1.2 Foundational Concept

Signed by most countries on Earth in 2035, *Mars Advancement and Residential Settlement Treaty* (M.A.R.S Treaty) declared that the Mars City State would serve a peaceful purpose, aiming to expand the horizon for humanity. It should not spread nationalism, and it is forbidden for any country to claim land on the Red Planet[1]. Land tenure on Mars would follow the MSA standard (specified in 5.2). The rest of the land on Mars was recognized as the "*Common Heritage of Mankind*.[1]"

People who choose to permanently reside on Mars are required to relinquish their previous citizenship, and thus they would only represent themselves. They become Mars citizens and are subject to Martian laws. To ensure a sustainable development on Mars, governments on Earth cannot interfere with political, cultural, and social decisions made by the Mars civilization. After signing the treaty, companies from respective nations were granted the clearance to gain profits from Mars: including but not limited to the trades on Mars' resources, usage of intellectual property developed on Mars, and participation in research projects. An era of progression thus began.

[1]Concept by Immanuel Kant in *Toward Perpetual Peace*.

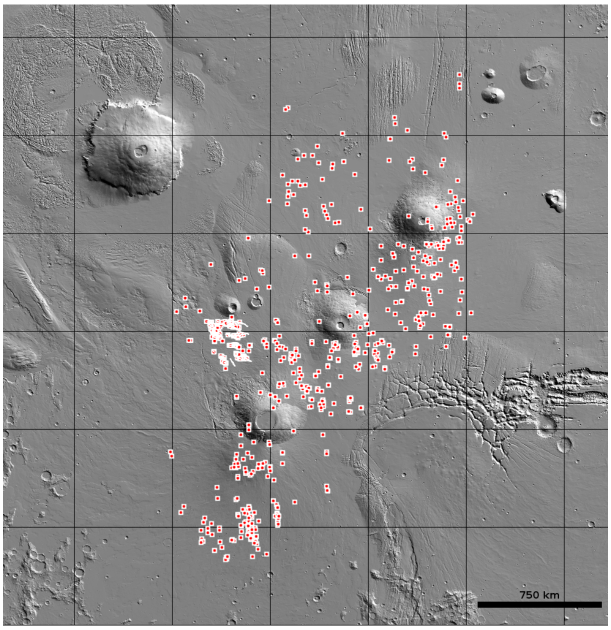


Figure 3: Cave entrance candidates detected by USGS. Image owned by USGS. City State (divided into five autonomous districts) is located to the South of Arsia Mons, the Southernmost mountain among the four.

2 A Subsurface Settlement

2.1 Site Selection

Martian near-surface caves are ideal locations for human settlement. These underground caves 1) have sufficient lateral extent to shelter humans from surface hazards, e.g.micrometeorite impacts, dust storms, high fluxes of UV, alpha particles, and cosmic rays, 2) can maintain near-pristine surfaces and 3) can minimize temperature variations and create relatively stable micro-climates[2].

Hence, the first million people city state is built in the region of Arsia Mons (8.35°S 120.09°W), which bears unique climate features that makes this place the best choice. First of all, located in the warmest temperature zone on Mars[3], it is the most energy-efficient place to maintain an optimum temperature inside the settlement. Secondly, the region consists of seven separate cave systems around the extinct volcano, along with hundreds of cave entrance candidates (Figure 2). Thirdly, glaciers are identified on Arsia Mons at both high and low elevations, which can be valuable resources. Fourthly, the three mountain system on the Tharsis plain provides an accessible expansion pathway for more city states in the future.

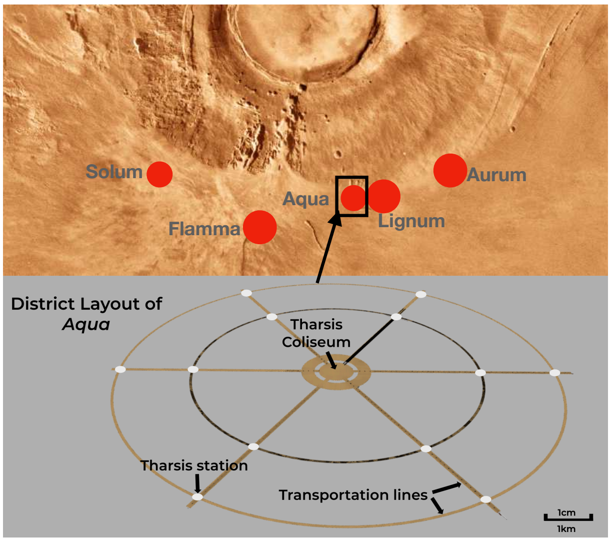


Figure 4: Layout of the 5 districts: Aurum, Lignum, Aqua, Flamma, and Solum. (Image of Arsia Mons from *Views of the Solar System* owned by Calvin J. Hamilton) and the structural layout of district Aqua.

2.2 Urban Concept

The Republic City State of Tharsis is located to the *south* of Arsia Mons, where there are denser caves and are later developed into habitable areas. Shallow and flat caves are ideal for human settlement; deeper and larger ones are usually enriched of geological evidence, making them ideal locations for scientific research[2]. Therefore residential areas are built in underground caves while transportation systems run above on the surface.

By 2120, the city state had developed five inter- and intra- connected *districts*: *Flamma* (the Capital district), *Aurum*, *Lignum*, *Aqua*, and *Solum*. These regions are selected after careful assessment and consideration, including the abundance of resources and their proximity to interplanetary spaceports, to ensure the diversity of the economy.

Each district consists of two layers: *Thar-Up*, which is the surface layer, and *Thar-Down*, the subsurface layer (See Figure 6). With a fan-like layout, *Thar-Up* runs the state's fastest transportation systems; a grand coliseum is located at the center, serving as a multipurpose entertainment center that hosts sports events and concerts. Multiple unmanned factory zones are constructed above ground, housing a number of 3D-printing, energy production, and resource extraction factories. *Thar-Down* hosts the majority of human activities, including administration, agriculture, business, residential, and research.

2.3 Architecture

Thar-Down provides Martians with ample residential spaces (See Figure 6). Buildings in Thar-Down are generally dome-shaped to better handle the pressure difference between the Martian ambient pressure and room pressure. Domes vary in sizes, and many of them are as large as a Stadium. They are constructed by giant 3-D printers in-situ using regolith [4]. Microorganisms are used to detoxify regolith, aiming to reduce highly toxic perchlorate[5]. In addition to regolith, layers of heat insulation and air tightening materials are cast in the dome wall to enhance strength, air tightness, insulation, radiation protection, and offer pleasing aesthetics.

Serving residential, recreational, and tourism purposes, Domes are designed with compact hexagonal modules to facilitate an efficient management of feed systems for oxygen, water, and energy. Lawns with a circular running track surrounds the periphery of each floor, providing residents with ample interaction space, which effectively soothes the *surface chauvinism* they may have. Each hexagon module consists of a small central garden and surrounding apartments. Corridors connect each module to the elevator lobby at the center of each floor. Residents can use elevators to go to different floors, the metro station in some of the sizable Domes, or go to *Thar-Up*. Domes are connected to each other via underground tunnels through which residents can easily travel between Domes (See Figure 6).

Feature: Skylight

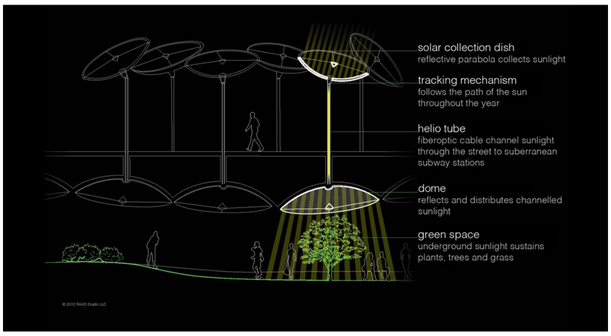


Figure 5: Skylight System. Image by *The Lowline*.

Though the lighting system could be easily implemented using LED lights (which are widely used at the beginning of the 21st century), natural sunlight is conducive to people's psychological health as well as architectural aesthetics.

A sunlight piping system conceived by James Ramsey and Dan Barasch[6] uses a system of mirrors, installed on the Martian surface and pivoting and rotating to follow the sun's path across the sky, to collect sunlight. Large parabolic dishes underground concentrate sunlight which is then funneled between a series of mirrors. Employing distributors – optical diffusers mounted to the ceiling made of anodized aluminum panels – the light is then spreaded over Martians' homes.

This unique system is able to produce a full-spectrum light efficiency of about 70 percent (losing only small amounts of light that are absorbed instead of reflected at each mirror touchpoint). For comparison, the alternative – collecting energy from solar panels and using that electricity to power LED lights – would create efficiency closer to 7 percent.

2.4 Key Infrastructure

Transportation Tubes

In order to protect public transportation systems from constant dust storms, all hyperloops and railways run in closed tubes, which are mostly 3D printed with regolith. Different sections of the tubes are contracted with different transportation companies, who compete to provide the best commercial services for residents and industries. Cargo tubes are shielded with aluminum to prevent charged particles from interfering with sensitive electronic devices. There are also transparent tourism tubes specially designed with radiation protection that offer tourists a wonderful panorama of the landscape.

Tharsis Station

Stations are built at the intersections of radial and peripheral transportation lines. Each station is a local center of transportation. A station has three layers. The top two layers are for commercial and tourism transportation, and the bottom layer is for private car transportation, which allows people to travel to less populous places or even the faraway Olympus Mons while enjoying driving by oneself. The skylight system is implemented around the station, collecting sunlight and directing it underground.

The Tharsian Cooperation implemented a revolutionary airlock system, consisting of *automated revolving doors* instead of two paralleled gates, is widely implemented in the City State for its two major advantages:

1) The revolving door perfectly accommodates a two-way traffic. Unlike the traditional airlock design of two paralleled gates, people can go in and out the same time, making this design is significantly more time-efficient.

2) The revolving door follows a "pressurized - depressurizing - depressurized - pressurizing" cycle. Take one section of the revolving door for example. When walking out of the station, people in spacesuits enter one section of the door and it starts revolving. The controller for this section begins depressurizing the air inside, so that when this section completely faces the outside world, the pressure difference is minimal, and people can exit safely and conveniently.

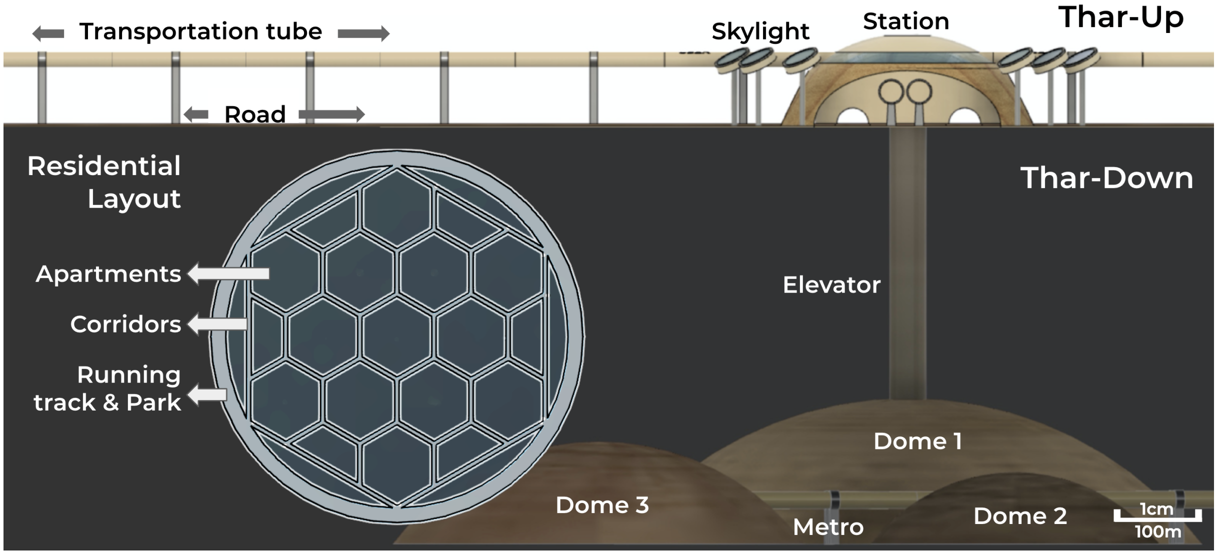


Figure 6: Side view of *Thar-Up* and *Thar-Down*. Sizes of Station and Dome vary in accordance with usable underground area. This image depicts a medium-sized one.

3 An Industrialized Mars

3.1 Automation

In 2035, a cargo ship was sent to Mars, carrying a fleet of 42 robots equipped with the most advanced AI system (at that time). They deployed themselves on the surface of the Red Planet, and first set up solar panels near the factory zone and greenhouses in the agriculture section. Then, for six months, they embarked on a journey of excavating proper materials determined by previous Mars missions. They, afterwards, divided into different groups to work on building 3D printing factories and setting up subsurface living spaces with airlocks, nuclear plants, the oxygen and transportation systems.

Meanwhile, note that in the same way that no human is perfect, there is no error-free machine. Therefore, the aforementioned robots were capable of self-repairing. Also, due to the delay in communication between Earth and Mars, each robot constantly ran a feedback loop to conduct diagnoses on itself. They bore the extreme environmental conditions on Mars, such as temperature, pressure, radiation, and dust. Importantly, the peace was carefully maintained between the first robots from Earth and their "brothers and sisters" additively manufactured on Mars.

However, with great intelligence and physical power, robots might bring security concerns. Hence, humans took extra precaution on their creations and employed the high-level concept of the *Three Laws of Robotics* suggested by Issac Asimov[7] to ensure that A.I. is designed to assist humanity and contribute to the social good.

Now in 2120, robots take an ubiquitous presence in various industries on Mars for different reasons. In the field of resource acquisition, the toxicity of substances on the Martian surface makes human excavation, inspection, and transportation in mining extremely dangerous. Therefore, robotic dogs were designed to replace humans in these tasks. Growth-monitoring robots work in the rotating hydroponics greenhouses, and use computer vision to determine the growing state of each crop in every six hours – something that human eyes cannot differentiate – and adjust the lighting and rotational speed according to results of numerous calculations. In energy plants, human inspection is no longer necessary thanks to the deployment of robots. Meanwhile, the extensive application of A.I. in education helps to guard against systematic bias and prejudices.

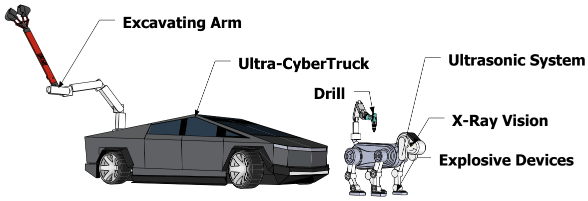


Figure 7: Ultra-CyberTruck and Robotic Dog[2].

3.2 Resource Acquisition

Metallic Material Extraction

87 miles away from the center of Arsia Mons, Olympus Mons is located at the northwest of the colony's urban area. As the tallest Mountain in the entire solar system, Olympus Mons is full of ore resources. A set of trans-mountain highways constructed at the Corporatization stage travel from Arsia Mons to where profuse resources are estimated to be at Olympus Mons. Tesla Ultra-Cybertrucks, the most popular vehicle for resource extraction, is an autopilot electric truck that feeds off its energy from the KRUSTY nuclear stations located along the road. It has four robotic arms for excavation and three automatic intelligent "robot dogs" which carry drills and explosive devices are on dock, totalling a carrying capacity of 20,000 pounds per Ultra-Cybertruck.

The mining process of one site is usually carried out by an assembly of 12 Trucks. When the Trucks are driven to a site where abundant targeted resources might be found, every truck releases its "robot dogs" to the nearby locations. Incorporated with computer vision, X Ray sensing, and metal detectors, the robots drive themselves to designated sites, drill holes through the wall, deploy explosive devices in the holes and determine the capacity of ores in that site after the explosion. If the capacity exceeds the designated standard, they will place beacons, which will be received by their parent Trucks and the Trucks will soon arrive and excavate the ores with robotic arms.

Raw materials are directly transported to processing facilities such as blast furnaces where raw materials go through the reduction and purification process. Refined materials are delivered to heavy manufacturing production lines through hyperloops.

Resource extraction and processing produce huge amount of tailings. The tailings on Earth have been damaging the environment outrageously, and tailings on Mars could have done so even more due

[2] 3D models from 3D Warehouse, Contributors: Jack L.,Birkholz A., Norbert S., Bart Gillespie, ///Eurasia — HHHR///

to substances on Mars that humans are not familiar with. To prevent tailings from hindering the future goal of terraforming Martian surface, the Environmental Agency on Mars has issued policies requiring tailings to be treated properly. A common practice is to let robotic devices decompose the tailings following the standard set by the Agency and convert to useful materials.

Water

Water is lifeblood of humans on Mars. The acquisition of water (and subsequently oxygen) is conducted in multiple ways. The most prominent method is to collect ice caps and produce water with the *Reverse Water Gas Shift Reaction*.

Ice caps are abundant in the Martian subsurface area, as well as the surface area of Arsia Mons and polar regions[8]. Cargo-hyperloops on a larger scale connect the City State to potential mining sites on the glacier of Arsia Mons, transporting Ultra-CyberTruck and CyberDogs. The CyberDogs for ice mining are equipped with hot water drills, and pumps the melted ice onto the CyberTruck storage. To purify the melted water from excessive amounts of perchlorate and other salts, the CyberTrucks are equipped with desalination devices which release IX resin to capture chloride ions from perchlorate[9]. Then the water goes through a standardized purification process and be transported back to the City State.

The other way to obtain water is the Reverse Water Gas Shift (RWGS). The process, conducted in facilities inside the City State, is to capture the profuse amount of carbon dioxide from the atmosphere, and reduce it with hydrogen to obtain water. [10]

$$CO_2 + H_2 \longrightarrow CO + H_2O$$

The reaction is endothermic, and the equilibrium constant given by [11]

$$\log K_{\text{eq}} = -\frac{2180.6}{T} - 0.0003855T + 2.4198$$

for such a reaction is very low at low temperatures, and therefore it is ideal to combine the facility with a molten salt nuclear reactor. Instead of pushing turbines, a portion of the heat from the hot molten salt, which can get as high as 1400 degrees Celsius[12], is used to heat up the reaction chamber for RWGS, and a portion of the heat converts to electric energy to run RWGS facilities. Carbon monoxide produced is captured and become supplies for other industries, such as metal processing.

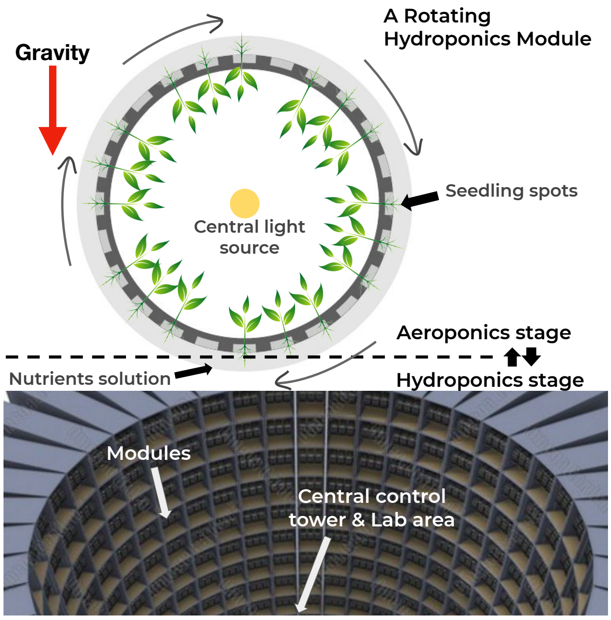


Figure 8: Rotating hydroponics System.
Upper part: a side view of the cylinder module. Plants are rotated vertically. Lower part: a fully assembled greenhouse rendered by Omega Garden.

3.3 Agriculture

A Rotating Hydroponics Greenhouse System

The unstable climate, toxic soil and frequent dust storms on Mars make it difficult to grow crops in the same way as on Earth before the complete terraforming. Instead of conventional space hydroponics, the Rotating Hydroponic Greenhouse System [13] is widely implemented to feed a million people. The system consists of hundreds or thousands of modules depending on greenhouse size. Each module is shaped as a cylindrical ring, with seedling spots on the inner surface. The module rotates vertically 360 degrees per hour around a central light source, which is also powered by skylight. Constant rotation activates auxins[13], the growth hormones, thus stimulate larger yields. Such rotation switches plants between hydroponics mode and aeroponics mode, saving a considerable amount of water and fertilizer and reducing the possibility of root diseases. Moreover, a cylindrical design means the plants capture almost all of the lumens emitted by the system's light source.

Agriculture experts have introduced "popularity" as an important metric of plant selection as population expands. The dishes served in Martian homes and restaurants are vastly diversified with the introduction of tomatoes, onions, cabbages, eggplants, carrots, garlic, spinach, pumpkin, broccoli, etc.

Food Printing and Meat Lab

3D printing and meat culturing is extensively used in the settlement. Foods coming out of the harvest station of the greenhouse go straight into the processing center. A portion of the output is made into food cartridges for the 3D printing complex that produces snacks such as chocolate and biscuits, which serve as emotion-boosting refreshments.

Raising livestock on Mars is both technically and economically difficult. Instead, meat is cultured in meat labs that produce clean and healthy protein sources. Cultured meat labs take cell specimens of common livestock from Earth to generate edible meat in labs[14]. The meat produced from the meat lab tastes almost nothing different than real meat, and is widely popular for its decent prices.

3D printed pseudo-meat is another option for meat-lovers. 3D food printers can transform the texture of a plant-based food into the texture of almost any meat. It is healthier, cheaper, more environmentally friendly and tastes almost no different from real meat. 3D printed meat, along with lab-grown meat have become prevalent on the Mars.

3.4 Energy

Integrated Energy System on Mars(IES-M)

IES-M is the integrated energy system that supports the life and production of one million people on Mars. The main sources of energy on Mars are solar energy, nuclear energy and wind energy.

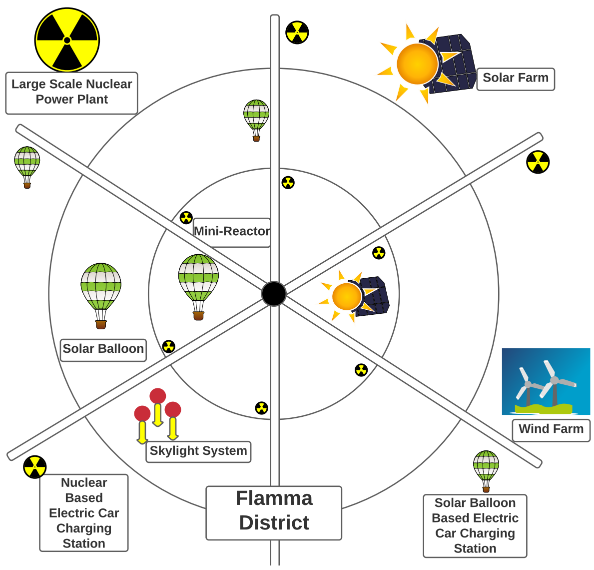


Figure 9: Energy System IES-M.

Every district of the colony is powered by its independent IES-M. Large nuclear power plants and solar farms make up the energy supply of most industrial productions; wind farms, mini-reactors, as well as solar balloons that are integrated into the residential grid power most of the residential area; Wind farms yield significant amount of energy during strong winds and dust storm when solar system does not function as well; transportation is powered by individual power stations supplied by mini-reactors and solar balloons, powering vehicles along the road. The electricity consumption in 2119 reached 49.2 TWh, and 48.7 KWh per capita.

Solar Balloons

Roughly 40% of the total energy supply of the entire colony comes from solar energy. The expansive area of undeveloped land on Mars offered a tremendous spatial advantage for constructing large solar power plants. However, the periodic dust storm, which can last for days and even months, would lead to shortages of sunlight and contamination of the solar cells, dysfunctionalizing thousands of solar panels[15].

Therefore, the colony creatively adopted a Balloon-Based Solar Power System. The analysis and calculations demonstrated that the density for helium balloons is well below the density of atmosphere at the desired height.The system uses Solar Balloons–helium balloons covered with solar panels–raised at the height dust storms cannot reach, enabling uninterrupted sunlight reception during daytime.

A Solar Balloon consists of a section of solar panel on the balloon, a control box that automatically adjusts the air composition inside the balloon, and cables that transmits electricity to the inverter on the ground. The sphere is fixed with a rotational

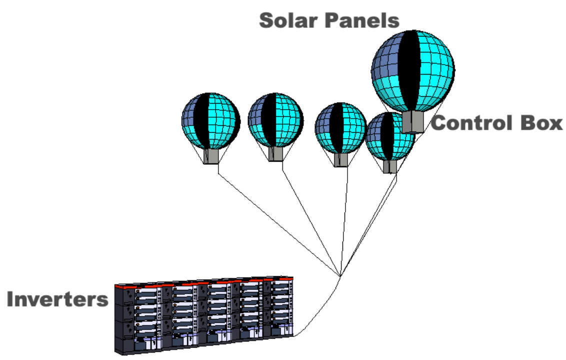


Figure 10: Solar Balloons[3].

[3] Modified with CAD models from 3D Warehouse, Balloon owned by lauwtJ, Inverters owned by Mati.

axis through the center. The control box feeds information about the direction of the Sun to its processor, which turns the balloon to the direction of the Sun. It also makes decisions whether to heat up or cool down the balloon to adjust the density and the pressure difference between interior and the atmosphere. The solar panels convert solar energy to electricity, and transmit DC to the DC to AC inverter on the ground to power individual households or electric car charging stations.

Nuclear Energy

40% of energy in IES-M is supplied by nuclear energy. Nuclear energy is provided by both large scale reactors built on the outskirts of urban districts and a web of mini-reactors incorporated into the residential area.

The mini-reactors are a more sophisticated version of KRUSTY (Kilopower reactor using sterling technology)[16], which is a molten salt reactor with a stirling convertor to connect to the core, converting the heat to kinetic energy and then to storable electricity. The radiation shielding prevents any potential damage to individuals. These reactors are capable of generating power ranging from 1 to 1000W, large enough to power an entire household. Every compartment in a structure (residential domes, factories, 3D printing stations etc.) is equipped with one such reactor, and all the reactors are located in the radiation shielding room, which is connected to every individual compartment. These reactors are popular among real estate contractors to meet the MSA standard for energy provision (See 5.2).

3.5 Communication

Local Network on Mars

Constructing a local network system on Mars is more challenging than on Earth. The severe climate condition on Mars and the frequent appearance of mountains and valleys make it harder for telecommunication stations to perform optimally, plus the low curvature radius of Mars reduces the field of view of these stations[17]. While these communication methods function well in certain areas, it is difficult for them to provide a global network.

Since the City State is located in the south of Arsia Mons in the low latitude zone on Mars, a group of satellites in Aerosynchronous Orbits with orbital inclination 0 to 30 degrees is the most economical way to construct a local network on Mars.

Satellites in Aerosynchronous Orbits are roughly 17,000 kilometers from the ground[18], forming a field of view of 23.6 degrees. The satellites, looking in the ground tracks in the "Mars Centered, Mars Fixed" coordinate, cover the whole Tharsis region enclosed in round groundtracks.

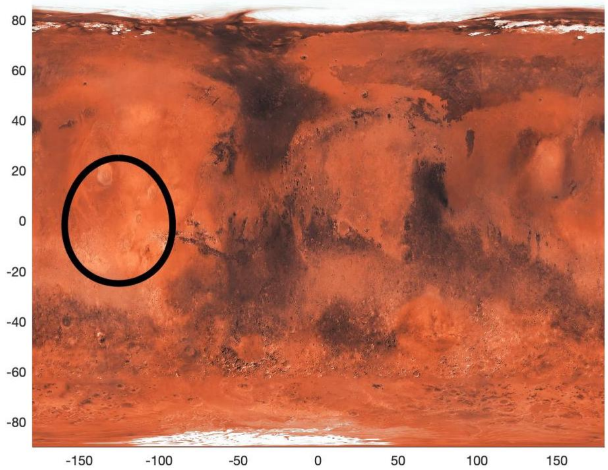


Figure 11: Tharsis region covered by satellites.

Future Outlook: Starlink-Mars

Starlink, a project proposed by SpaceX, is essentially a satellite constellation in low earth orbit, using laser instead of traditional radio waves to achieve higher internet speed and reduce delay of signals. Such system is perfectly suitable for Mars in the future when the majority of land on the Red Planet is colonized. Currently, a number of engineers and technicians are dedicated in designing the satellites suitable for Martian conditions to create a Starlink on Mars.

Internet on Mars

Building the Internet on Mars was a great challenge for the first group of engineers. The physical distance between Earth and Mars makes it impossible to synchronously access terrestrial internet servers on Mars. Every click comes with a waiting time of 10-20 minutes depending on the relative positions of these two planets. It is the most ideal to duplicate major internet servers onto Mars.

Beginning in the early preparation stage of the City State, for every internet server on Earth, a counterpart would be present on Mars. Every update on the internet on one planet reciprocally transmit to the servers on the other.

Traditional radio waves would not satisfy such a high volume of constant workloads due to their low data transmitting rate. Laser is a better option. Optical Payload for Lasercomm Science (OPALS)[19] has been able to achieve a multitude times of traditional speed of data transmission. When transmitting from Mars to Earth, servers on Mars uplink data to satellites on the Low Mars Orbit, which then transmits the data to the International Space Station, which downlinks the data to ground stations on Earth, and vice versa.

Solar Conjunction and Relay Stations

Oftentimes signals have to travel farther to get to the other planet, especially during the Solar Conjunction when every two years Earth and Mars are on radially opposite sides of the Sun and there is a two-week long "blackout" time when most satellites become incommunicado[20]. At the early stage of the City State, it pauses most of the communication with Earth, and uses this period to repair and upgrade existing communication devices. Later on, four groups of communication satellites are launched onto the Lagrange Points L4 and L5 of Earth and Mars respectively. They carry signal repeaters, amplifiers and are equipped with information assurance system. These satellites serve as relay stations for signal travelling between Earth and Mars, maintaining the interplanetary communication continuously.

3.6 Extraterrestrial Outpost

Phobos, one of the two Martian moons, is a destination no tourist wants to miss. It has only 0.1% of the surface gravitational pull of the Earth: a 150-pound (68 kilogram) person would weigh only two ounces (68 grams) on Phobos. In this natural microgravity environment, the customized *roller-coaster* is usually kids' favorite in amusement parks. Better yet, there are two gigantic space elevators currently under construction, which will transport people from and back to Mars while enjoying their dinner in the floating restaurant.

The Phobos Lab (nicknamed "the Crazy Lab") experiments on mind-blowing technologies, and one such undertaking is to build a small-scale model to simulate a dyson sphere which wraps up a star. Ice reservoir[4] on Phobos provides water to be made into rocket propellants [4]. Spaceships dock on Phobos Stations and refill their tanks – before starting off journeys to the moons of Jupiter or nearby solar systems.

[4] Phobos is similar to the C-type asteroids composed of carbonaceous surface materials. It has significant porosity, which led many scientists to think that it had a substantial reservoir of ice at the beginning of the 21st century.

4 An Exo-politan Commercial Center

4.1 Economy of the City State

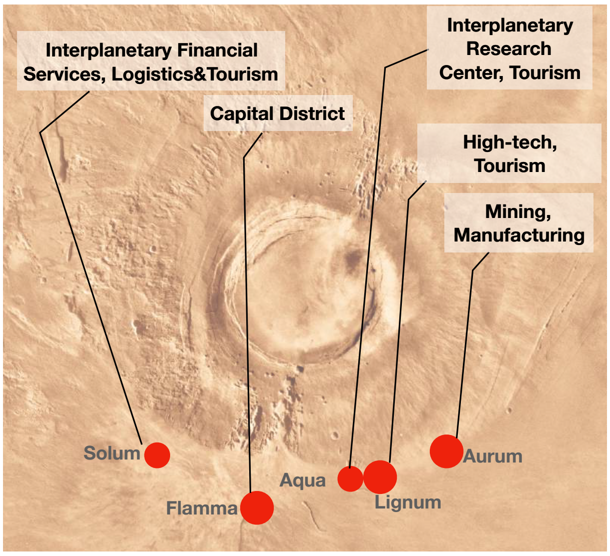


Figure 12: Districts with respective specification in economic sectors.

The Primary Sectors

The Primary Sectors of the City State include Ore Mining, Water and Oxygen Production, Agriculture, and Manufacture. Ore Mining and other raw material extractions, processing and heavy manufacturing are mostly concentrated in Aurum, the district surrounded by abundant ore resources and connected by inter-mountain highways. Companies construct raw material processing facilities like blast furnaces. Much of the refined raw materials go into autonomous factory assembly lines. Inter-district hyperloops connect these facilities directly for distribution to every district. Many households have adopted 3D printing based customized light manufacturing in their own living space. Processed materials such as PLA, steel, and glass are directly distributed to individual 3D printers for individual households.

The Secondary Sectors

The Secondary Sectors of the City State include advanced R&D, and cutting edge technology industries. These mostly take place in Lignum and Aqua, which are called "twin cities" for their interconnectivity and tightly related economic activities. Lignum, utilizing its proximity to the Aurum, has been a hub of cutting edge technology industries like Advanced Aerospace and Astronautical Industry, Advanced Agriculture and Advanced Computer and Robotic Productions. Right Beside Lignum, the "twin" Aqua is an interplanetary cosmopolitan city for higher education and research. Frequent Academic exchange programs between Mars and Earth usually take place in Aqua.

The Tiertary Sectors

The Tertiary Sectors of the City State include interplanetary financial services, interplanetary trade logistics, tourism as well as entertainment. Every year, thousands of people and millions of tons of products depart to and arrive from Earth at the Musk Space Center near Solum. As a result, logistics companies, financial institutions and tourist agencies located in Solum have been big beneficiaries of interplanetary activities. The service industry has become a major economic sector in Solum and made up a towering percentage of Solum's GDP. Tourism is an huge economic contributor to every district. Most visitors from Earth like visiting the Capitol Building, Research Centers and Universities on Mars. The most frequently visited districts are the "Twin Cities" Lignum and Aqua: Due to the presence of advanced technology and cutting edge research, the "Twin-Cities" has drawn enormous public attention. Every Mars year, Therefore the entertainment industry, such as Mollywood Martian Movie Industry (MMM), and Microtonal Martian Music (MMMc) Industry have been booming in the Twin-Cities.

Consumer Manufacture with Additive Technology

The rise of additive manufacturing changes the way people think about production on Mars. As 3D printers are being produced by 3D printers at lower prices, and convenient modular computer programs and plugins become widely available, it is very popular for individuals to print and produce their own everyday commodities rather than purchasing from retailers. Moreover, for relatively complex and voluminous items, their productions are carried out in local 3D printing centers. Traditional household product businesses have not become obsolete, rather they are now reduced to design businesses that retail 3D CAD designs to customers. Such change also creates entrepreneurial opportunities for individual developers who may upload and sell their designs at online DesignStore. On Mars where the geological conditions make it even more expensive to construct light manufacturing factories, additive technology plays a huge role in the lives of residents.

4.2 Bilateral Currency System

The rise of decentralized cryptocurrency using the blockchain system in the 21st Century has resulted in unprecedented popularity of bitcoin on Earth. By 2050, in the United States, for every one dollar a person earns, 40 cents on average had been invested in cryptocurrency. However, due to the lack of centrality of such a currency, it is very difficult for an outside force such as the government to regulate the market on the brink of financial crisis. The Republic City State of Tharsis adopted a Bilateral Currency System, consisting of both decentralized Blockchain Based Cryptocurrency System(BBCS) and a centralized currency system under the regulation of *The Martian Reserve.*

Galileo: A Blockchain-Based Cryptocurrency

Blockchain Based Cryptocurrency System(BBCS) is a decentralized peer-to-peer payment network. The system is created by the Tharsian Corporation, and is later ratified as one of the official currencies in the City State. Similar to Bitcoin, it does not have a centralized bank, and is under no control of a central government[21]. Users can process transactions in order to be rewarded by the system (Galileo Mining). The currency of BBCS is called Galileo (MSG). Par the M.A.R.S. Treaty, the exchange rate of Galileo to USD was 1:1 when the system was first established, effective at the beginning of Sectionalization, and is subject to fluctuations later. Galileo consists of a pair of public key and private key, which allows the coexistence of both transparency and privacy. Unlike Bitcoin, Galileo does not half, which puts no limitation on the number of Galileos in the market. Citizen Economic Key (CEK) is required for registering for Galileo wallets. Citizen Economic Key (CEK) is assigned to everyone at birth/landing to conduct economic transactions and prevent fraudulence. It ensures that Galileo is safe and portable, and enables purchases through fingerprints and/or face recognition.

Kepler: A Regulated Cryptocurrency

Kepler is similar to traditional currency. Par the M.A.R.S. Treaty, the exchange rate of Kepler to USD is 1:1 when the system is first established, effective at the beginning of Sectionalization, and is subject to fluctuation later. The exchange rate to other currencies is subject to free floating rate system. Kepler is issued by and is under the regulation of the Martian Reserve, which is under the administration of the State government.

The mission of the Martian Reserve is to maintain monetary market order and regulate economy. The Reserve has several primary strategic goals with interrelated and mutually reinforcing elements:

- Utilize its ability of adjusting interest rates to regulate the market.
- Promoting a transparent, sustainable, and effective interplanetary trading system.
- Foster the integrity, efficiency, and effectiveness of Board programs and operations.

4.3 Dynamics Between Two Currencies

While many other cryptocurrencies are also available on Mars, Galileo and Kepler maintain their status as the dominant two currencies. The coexistence of a centralized currency system and a blockchain based decentralized currency system allows citizens to enjoy the benefits of both. Galileo and Kepler are at constant competitions as well as a dynamic equilibrium with each other. When the Galileo market seems too volatile, or Galileo banks seem unreliable, people would switch to Kepler. When government regulations seem to hurt the market, or the economic opportunities in the Galileo market arise, people would switch to Galileo. The competition of two currencies allow each system to perfect themselves, and therefore fostering a more stable monetary system.

Special Features of Galileo

Product Certificate and Smart Contracts

Due to the long distance between Earth and Mars, Blockchain becomes especially vital in product transportation and logistics systems. Every product, whether shipped from Earth or Mars, bears a series of digital time stamps that indicates the information of the transactions, e.g. departure and arrival status and locations. The automatic tracking system, enhanced by the smart contract systems, which are the mutual payment agreements made by purchaser and retailer, makes Earth-Mars or intra-Mars trading reliable and efficient.

Legal documentation and Digital Voting

The tamperproofing of BBSC protects the effectiveness of intellectual properties and legal documentation. Public office elections also adopt BBSC. While not everyone is required to have Galileos in their account, each resident may cast their votes via BBSC through which their CEKs must be verified.

4.4 Industry Profitability

The Committee determined that the Mars' economy was *autonomous* in 2091, ensuring full independent sustainability of Mars even in absence of the Earth. In achieving such autonomy, Mars' domestic economy shares a similar variety of industries to Earth, with a heavier emphasis on agriculture, manufacture, and R&D. The interplanetary economy was built upon the transportation of intellectual properties and resources, research, and tourism.

Trade on manufactured goods

Over the 21st century, the additive manufacturing technology has matured rapidly. While both Mars and Earth are able to produce all essential goods if needed, the cost for manufacturing certain products overwhelms the cost for producing it on the other party plus the transportation fee. Thus, interplanetary importation and exportation usually take place for light-weight products that one party has relative advantages to produce.

Trade on natural resources

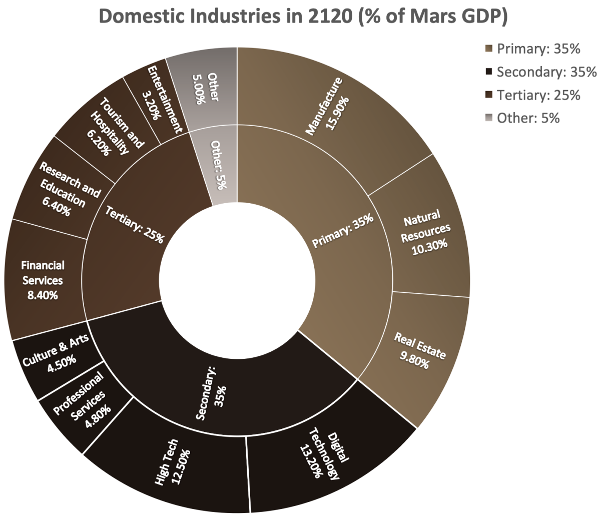
The discovery of abundant natural resources on Mars triggered a “gold rush” in the 2050s. Over half a century, Mars experienced a population boom, various environmental issues, protests, and legislation of the Martian Natural Resources Law. By 2091, there are 85 interplanetary companies left that are involved in the trade of natural resources, such as deuterium, on Mars.

Licensing of Intellectual Property

As Dr. Robert Zubrin predicted[22], Mars' economy thrived thanks to the transportation of ideas: the harshness in the new physical environment as well as a prevalent technological culture prompt Martians to continually ask themselves: *How to make it better?* Especially at the Corporatization and Sectionalization stages, science and technology were romanticized; on average every three Martians had a patent. Breakthroughs in automation, energy production, biotechnology, manufacture, quantum computing etc. happened too often to make them news. These inventions brought a huge amount of profits to Mars even as they revolutionized the society and advanced living standards on both Mars and Earth.

Export and Import of Artworks

An entirely new lifestyle on Mars is conducive to generating a new understanding of ourselves, our



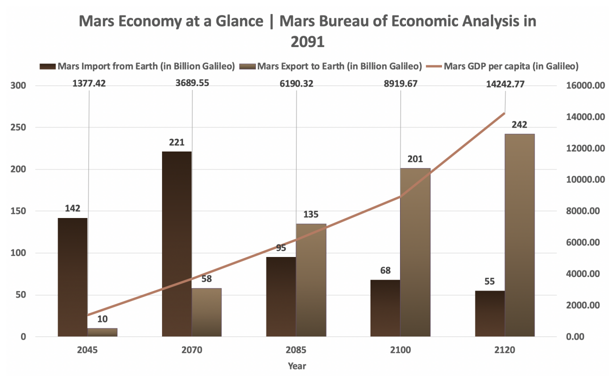


Figure 13: GDP by sector and Interplanetary Commerce.

world(s), and ultimately, the human condition. Martian artists have produced numerous mind-blowing literature, music, and paintings, which sometimes go so far as to redefine the perception of "*beauty*."

These artworks have been exported to Earth in the digital form, inspiring generations of young people to be the next settlers. Likewise, the work of artists on Earth is exported to Mars, generating an artistic dialogue between planets.

Research

Due to different physical properties in the ambient environment, Mars has attracted a large number of biologists, physicists, chemists, material scientists, and geologists from Earth. Hence, the research institute to which they belong pays a fee for them to be a visiting scholar on Mars. The results of their research, such as medicines, nano-structure products, and even spices have generated a tremendous amount of revenue on Earth. Main areas the research on Mars has been especially successful in looking for solutions to hunger issues (agriculture), better water processing methods, sustainability and higher recycle efficiency, increased energy efficiency, better build material, more effective communication methods, etc.

Tourism

The expression of "travel around the world" was switched to "travel around the world[s]" when the number of tourism programs exploded in the 2060s. At that time, thanks to better rocket technologies, the price for tourist tickets was reduced to 42,000 USD per person, a 90% decrease from the 2030s. The Mars Committee also launched a scholarship program on Earth, which offers free tourist tickets for the scholarship's recipients, to inspire the next generation. With the increasing number of native Martians, visiting Earth became popular at the end of the 2070s. Its price usually varies from 10,000 Galileo to 30,000 Galileo (equivalent to 24,000 USD and 72,000 USD in 2020) depending on different tourism companies. In total, there are 87,746 tourists visiting Mars and 12,782 tourists visiting Earth in 2091.

Entertainment

Music, movies and sports have been unprecedentedly popular after thousands of artists and athletes immigrated to Mars. Mollyhood Martian movies have become as popular as Hollywood movies during 2000s. Movies are usually released on Mars 8 months prior to the releases on Earth. Thousands of Martian movie fans from Earth would travel to planet Mars to see the movies upon their release. Sports are huge tourist attractions and revenue generators.

Unique Martian sports draw enormous profit from interplanetary tourists. The State government constructed The Tharsis Memorial Coliseum, a sports center that has the full capability of hosting Martian Olympics. The Center of the Coliseum is the court for Kulamu, a new sport born out of low gravity environment (see 5.5) . While VR tickets are widely available, the front row ticket price for a Kulamu match reached as high as 20,000 Galileo (equivalent to 48,000 USD in 2020).

4.5 Trade and Regulations

Interplanetary Trade

From the early stages of the colony – Corporatization and Sectionalization – there was a huge trade deficit when Mars had not established its essential industries. Meanwhile, the transportation fee of $500/kg from Earth to Mars gave startup businesses on Mars considerable hardship obtaining necessary raw materials from Earth. To compensate for that, in the early stages, businesses can file for subsidies for the transportation fee from the local government. The amount of compensation gradually decreased as the economy on Mars grew matured.

The transportation fee of $200/kg from Mars to Earth still poses setbacks for the businesses exporting goods from Mars to Earth. To help enterprises on Mars thrive, the central government continues to provide subsidies to enterprises whose profits mostly rely on exports to compensate for the high cost of transportation.

The central government is expected to repeal its subsidies regarding importation when Mars has developed its capacity for the research and development of interplanetary transportation industries. The high transportation fee will stimulate the market to optimize the technology and find ways to reduce the cost. As various interplanetary transportation methods improve, industries across Earth and Mars will eventually be in a nearly perfect competition.

Price Ceilings and public owned productions

Necessities like water, oxygen, and protective garments are life-concerning for any individual. Therefore, although there is no barrier of entry for private industries to invest in these markets except that they must qualify the regulation standards, there are price ceilings for these necessities as the price surge of these products can be life-threatening on Mars. Such price ceilings would divert private businesses from participating the productions of the goods, e.g. the excavation of ice caps and the processing of perchlorate water. There the public funded state owned and district owned production companies would step in. As a result, 90% of the production of water, oxygen and Martian suits remain publicly owned. There is a small percentage of private companies in the markets, endeavoring to achieve productions of these necessities at lower costs and outcompete these public owned companies. While the public owned entities ensure the provision of these necessities to the majority of people, private companies seek to provide residents' with luxurious experience.

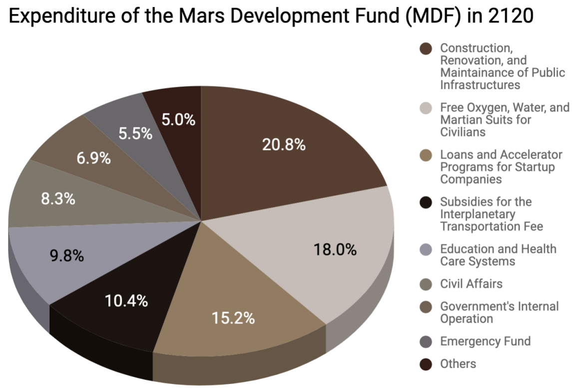


Figure 14: Expenditure of MDF in 2020. A significant amount of the MDF goes to infrastructure construction and necessity provision.

4.6 Tax System

The existence of tax revenue is dependent upon the emergence of a central governmental entity and private property. Since both of the conditions were met after the Corporatization stage, a tax system was developed on Mars to ensure that its government was operated based on the interest of Mars citizens, who pay for the tax.

The major components of the Martian tax system are similar to those on Earth – Enterprise Income Tax, Personal Income Tax, Land Value Tax, Consumption Tax, etc. – though the tax rate is generally more lenient compared to that on Earth. To encourage innovation and the application of innovative solutions, profits directly made by research and development centers are tax-free, and that any profits individuals/companies gain from using an intellectual property licensed in the recent ten years enjoy a tax rate cut to half.

The federal tax collected on Mars flows into the Mars Development Fund (MDF), which was set up at the beginning of the Preparation stage, receiving individual and corporate investments, crowdfund, and cash from ticket sales and bond and stock to financially support the City State's long term development.

MDF provides residents with well-maintained city infrastructure, sources of water and oxygen and management of civil affairs, as well as loans and starter programs to startup enterprises on Mars. In the later years, MDF continues to treat tax collected as investment received, enabling the Mars Committee to write proposals on how to spend MDF every two years, and Martians vote.

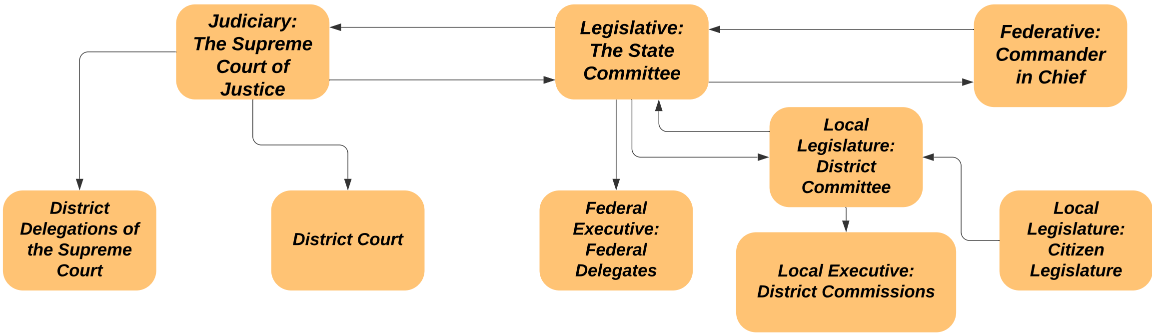


Figure 15: Government Branches.

5 A Vibrant Community

5.1 Government Structure

The Republic City State of Tharsis is a federalist republic city state, under which the primary political entity on Mars is *District*. Each district is highly autonomous under the constitution upheld by the State Government. The State Government consists of the *The State Committee*, *the Supreme Court of Justice* and *the Commander in Chief*, as well as the *Federal Delegates* in districts. The District Government consists of *District Committee, Commission, Court* and *Citizen Legislature.*

5.2 Land Ownership

The general principle: To encourage more settlers onto Mars, individual entities or collectives can obtain the ownership of the land they make habitable. The habitability is governed by the Mars Settlement Administration Standard (MSA Standard). The tenure to land is granted to an entity or collective by assessing the portion of the land with the MSA Standard.

Legal Protections of Properties

- The protection of the land tenure is primary to governments.
- No existing sovereignty on Earth can claim land for the uses of national interest.
- No land shall be claimed by any entity without being made habitable.
- An entity or collective has the right to trade the land with other entities or collectives. An entity or collective can be delegated by another entity or collective to make the portion of the land habitable, and the tenure of the land belongs to the entity or collective which pays for making the portion of the land habitable.
- The tenure of the land continues as long as the portion of the land is habitable. When the holder of the tenure is deceased, the tenure is granted to the delegate the holder appoints to. If there is no legal form of will that claims the succession of the tenure, the portion of the land will be held by the district government.
- The central government is prohibited to impose property tax. The District government collects no tax when no economic activity is being conducted on the portion of the land.

MSA Standard Overview

Structure stability	The structure(s) must pass the basic stability tests.
Material Durability	The material must be in good condition, and able to last for at least 50 years.
Oxygen Supply	All compartments of the structure must maintain oxygen concentration of 21%. Redundant oxygen generators must be provided and accessible all the time in every compartment of the structure in addition to the functioning one.
Energy Supply	All compartments must be connected to at least one reliable power station for the proper functioning. The minimum purchase of energy is the minimum energy consumption of all properly functioning devices in the structure.
Health and Emergency	All compartments of the structure must be connected to the emergency rooms where medicines, first-aid kits, emergency oxygen supply must be sufficient.

Table 1: MSA Standard Overview.

The State Committee	Consists of members representing every district, elected every four year; Is in charge of federal legislation; Creates federal agencies, but executions rely on the District Delegates.
The Supreme Court of Justice	Arbiter of the law; The judges are selected by the State Committee.
Commander in Chief	Is in charge of the federal military with the consent of the State Committee; Deals with diplomatic relations with political entities on Earth, as well as on terrorism and civil unrest.
District Committee	In charge of district legislature in accordance with federal legislature; Each member is elected every two year
District Court	The judges are selected by the District Committee.
District Commission	Consists of one Commissioner, cabinet members and District Agencies; Executes Federal and District Laws; The Commissioner is elected every four year.
Federal Delegates	Agencies enacted by the State Committee on district level that executes orders from the State Committee on a district level.
Delegations of Supreme Court	Examines the consistency between district law and federal law; Arbitrates conflicts between District Commission and Federal Delegates.
Citizen Legislature	An institution on district level of which any private citizen of that district can become a member through qualification and selection; Drafts bills as a second party beside the District Committee. Bills must be approved by the District Committee to become the law, if approved by the District Committee can also be referred to the State Committee, and become federal law once approved by the State Committee and ratified by over half of all districts.

Table 2: Definitions of Government Offices.

5.3 Individuals on Mars

One can become a citizen of the City State through birth, technical immigration or investment immigration. Technical and investment immigrants renounce their nationalities on Earth and become full Martian citizens once they arrive. Each individual is assigned with a Citizen Economic Key, with which they can be identified in economic and political activities.

Job Opportunities on Mars are diverse and abundant. Nearly 50 percent of the citizens have expertise on STEM fields. At the same time, many of them work as managers of their neighborhoods, districts, or the entire City State. With the advancement of automation and additive manufacturing, less than 5 percent of the workforce produce all manufactured goods on Mars. Freed of heavy labor input in the manufacturing industry, a significant number of people choose to work on design and marketing. Artists, musicians and movie producers are also come to Mars in quest for new inspirations.

5.4 Education

Civilization is in a race between education and catastrophe. —H.G.Wells

AI

There were two global problems in the education system at the beginning of the 21st century. First, "the rich become richer, and the poor become poorer." When education was becoming a business, the chance that a kid from a poor family receiving superior educational resources was not promising enough to confront social stratification. Second, however, while reinforcing education's role as a society's level ground, and thus placing all students on the same standard, students lose their opportunity for personalized educational development.

To solve these issues, Artificial Intelligence (AI) was introduced in the Education system on Mars. Everyone has a personal — and sometimes lifelong — AI, who possesses the entire library of educational resource that was heretofore produced. Every student is assigned an access to the AI education system, which designs education plan for every learner, and adjusts according to the learner's intellectual and personal development. The education and AI bots are free for everyone to provide equal opportunities. This way, from birth, every Martian receives the resource they desire.

Principles

The initial Martian Education system was also established by absorbing research findings in neuroscience and psychology. The clear border among grade levels and disciplines was determined to be unscientific, outdated, and thus abolished[23]. Instead, students learn by exploring their curiosities and *asking questions* — what? why? how? — and diving into them. Their personal AI acts as a mentor who guides him/her to explore questions.

The physical school was replaced by the concept of "community": students who live in the same community carry out collaborative projects. Each student spends half a day doing projects and collaborating with others. In a project, they may want to make something, improve something, shoot a film, or study a social issue, etc. The number of people in a group ranges from 2 to 100, and is determined by the learner's own will as well as AI's observance. Each project is usually conducted over a week, but it can also be longer through group members' discussion. Sometimes like-minded people gather up and form a group, and sometimes they come from distinct backgrounds. They are also always encouraged to visit experts and scholars if they like.

Education Plan

The curriculum for students younger than 12 is composed of question-learning, general education (literacy, numeracy, and history), projects, touring around Mars, and sports. For students older than 12, they have question-learning, projects, apprenticeship — choose a favorite industry and "intern" for at least six months (if they change their minds, they can choose again afterwards) — and general education. In addition, there are also educators on Mars who actively research and improve on the current system. In terms of innovation, it is also crucial to seek out faults in defaults. Therefore, the Martian kids are constantly reminded that everybody could be wrong to encourage them to actively challenge the existing framework.

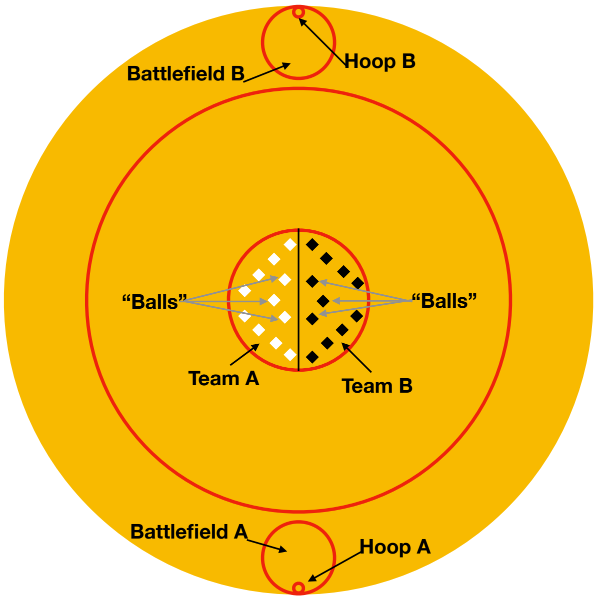


Figure 16: Kulamu Court.

5.5 Martian Sport: Kulamu

Kulamu, or Bodyball, is a new sport born out of traditional basketball in the low gravity environment. It is played between two opposing teams, each of 8-11 people, in a circular court. Three people in one team are designated as "balls." The main objective is for the "balls" of each team to jump into the opponent hoop and defend the opponent "balls" from jumping into their own hoop. Such a sport would be nowhere near possible in Earth's gravitational field, but the natural low gravity of Mars offers the ability for average people to jump 1.5 meters high and thereby making such a game viable.

A Kulamu court usually has the radius of 100 feet, surrounded by walls of 20 feet. The hoops are 20 inches in radius, and are 8.5 feet above the floor. They are 4 inches thick, made of stainless steel to bear the weight of a person. The floor and wall of the circular court are made of elastic materials, making them perfect trampolines. Players are required to wear bubble suits, which contain their bodies into airborne, elastic protective suits that look like bubble balls. In such a highly elastic and low gravity environment, an average player can jump as high as 8 feet[24][25]. Players who act as a "ball" usually break through the defense of opponents, make a jump under the assistance of their teammates, grab the hoop and then extend their bodies into the hoop to score one point for the team. Other players assist the "balls" to break through opponent defenses and defend opponents from scoring.

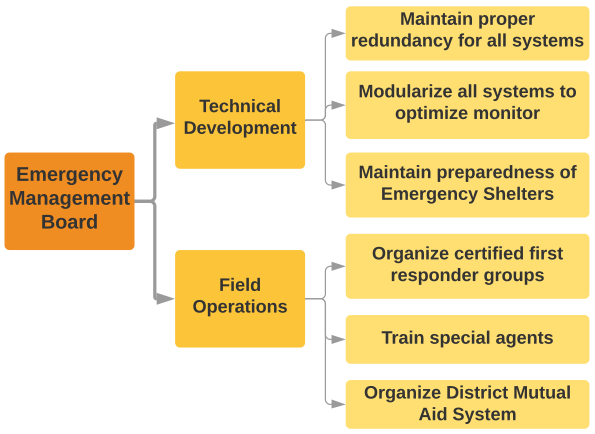


Figure 17: Responsibility of the Emergency Management Board. The Board is responsible for Technical Development and Field Operations, which branch out to many individual subsystems.

5.6 Emergency Management

The Mars Emergency Management Board is responsible for the overarching emergency programming, which encompasses technical development and field operations.

For technical development, the optimization of infrastructure is extremely important. To guarantee robust and seamless daily operations in the harsh Martian environment, *redundancy* [26] and *modularity* are two key features.

For redundancy, all critical systems such as oxygen, water, food have independent power feeds from both solar balloons and nuclear reactors so that no interruption of electricity occurs if one power feed fails. Each district also has an Emergency Shelter which is able to supply oxygen, water, food, and power for all district citizens for one month.

Examples of modularity includes the transportation tube system, hydroponics system, and hexagonal residential systems. When emergencies occur, locations can be pinpoint down to specific modules, reducing the time for diagnosis and enabling a faster replacement of the malfunctioning module.

Field operations programming includes 1) certified first responder groups, such as emergency medical technicians (EMTs), who conduct small-scale operations as soon as an emergency takes place, 2) special agents who deal with problems that require advanced technical knowledge, and 3) mutual aid of supplies between districts when problems escalate.

The Management Board is responsible for the recruitment, training and organization of all three branches.

6 Future Outlook

While the life in this meticulously engineered subsurface settlement on the Red Planet is truly ethereal, Martians are destined to break through the soil, sprout to the surface and eventually transform this planet to the one we originated from.

The difficulties in achieving these aspirations, nevertheless, are still enormous. Martians need to carry out a multi-centurial project to thicken the atmosphere on Mars by releasing greenhouse gases from ice caps and underground. During this process, Martians will gradually move up to the surface in settlements protected from extreme temperatures, dust storms and solar charged particles, and transform the toxic Martian soil so plants can grow.

Aside from these known difficulties, Martians must be both technologically and mentally ready for the unpredictability of the future. Should there be unknown exoplanetary virus on Mars that humans are vulnerable to, they must be ready to take contingent measures against it. At the same time, upon the journey of searching for life, humans must ensure that Mars is protected from human contamination. No one would want to see that one day we discover life on the Red Planet only to realize they have been casualties of our carelessness.

However, challenges have only been driving humanity forward since the dawn of civilizations. We have every reason to believe that the dream of becoming a multiplanetary species will come true with our wisdom and indefatigable spirit of exploration, equipped with new technologies in years to come.

7 ...And More

Designing a city state on Mars of one million is a challenging yet exciting endeavor. A 20-page proposal can only address the tip of the iceberg. Therefore we decide to further our work and post updates on our website *Tharsians*: http://www.tharsians.org

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