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The Dvaraka Initiative: Mars's First Permanent Human Settlement Capable of Self-Sustenance

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Abstract: From the farthest reaches of the universe to our own galaxy, there are many different celestial bodies that, even though they are very different, each have their own way of being beautiful. Earth, the planet with the best location, has been home to people for as long as we can remember. Even though we cannot be more thankful for all that Earth has given us, the human population needs to grow so that Earth is not the only place where people can live. Mars, which is right next to Earth, is the answer to this problem. Mars is the closest planet and might be able to support human life because it is close to Earth and shares many things in common. This paper will talk about how the first settlement on Mars could be planned and consider a 1000-person colony and the best place to settle on Mars, and make suggestions for the settlement's technical, architectural, social, and economic layout. By putting together assumptions, research, and estimates, the first settlement project proposed in this paper will suggest the best way to colonize, explore, and live on Mars, which is our sister planet.

Keywords: Mars colonization; Jezero; thermomechanical coating; asteroid mining; space tourism

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1. Introduction

The purpose of this research is to showcase team Dvaraka's (The team picked "Dvaraka", the city with many gates, to represent their goal of launching a new age of space exploration) entry for the Mars Colony Prize design competition that was organized by the Mars Society.

Mission

The hope that humans will one day go beyond the surface of the earth is inextricably linked to the notion that discovering uncharted territories would lead to the discovery of untold riches and possibilities. In the past, cultures that had acquired complete dominance of their environs had stopped developing and had become stagnant. This was because they had no competition for their dominance. In order for mankind to maintain its current rate of exponential progress, a new frontier is required. Mars, fortunately, is a fresh frontier that exists and is waiting for us to go there [1].

Among the celestial bodies near Earth, Mars certainly is the most habitable planet in our Solar System [2,3]. Wernher von Braun's "The Mars Project" was the first serious study that brought the concept of colonizing Mars from the world of imagination into the realm of the feasible [4]. After that, many research studies and projects were published regarding the colonization of Mars [5–9]. Traditionally, this discussion has been the monopoly of technical aspects with marginal participation from non-technical aspects. In this study, we will investigate both the technical and non-technical factors involved in the development of the first human colony on Mars that will be self-sufficient. Although the scope of this article is ambitious in nature, most of the technology that has been discussed in this study has a technological readiness level (TRL) of 7 or more. Moreover, the timeline of the mission starts in the year 2036 by which the apparatus and methods discussed in this study will become TRL 9.

2. Phases of the Dvaraka Initiative

In order to establish The Dvaraka Initiative, several pieces of literature were studied, and assumptions were formulated based on what was learned through placing the issues in their historical context and seeing the growing motives for technological advancement. Firstly, we assume that multiple robotic, sample return, and human return missions shall be conducted before The Dvaraka Initiative is undertaken [10–14]. The technology required to support humans for even a short duration mission is still under development and given the environmental dangers and difficulties in supporting the mission, it is here deemed necessary to test the required technology in situ, through return missions. Second, it is assumed that the early stages of the mission will require a regular resupply of equipment and raw materials from Earth until Dvarakans (Inhabitants of Dvaraka) are able to provide resources for themselves. Finally, it is expected that the technology necessary to safely transport a minimum of 85 tons of cargo to the surface of Mars using 1100 tons of propellant will be proven and available for deployment by the year 2030 for which, a combination of liquid methane and liquid oxygen (CH_4/O_2) that will have a mixing ratio ranging from 3:1 to 3.5:1. (O_2:CH_4) will be used as propellant [15,16]. Considering the end goal of self-sustainable human settlement on Mars, complete cooperation of Dvarakans is assumed for the total initiative. More so than all the engineering and logistical challenges, self-governance and the complete support of Dvarkans will be much more difficult to achieve. To enable new human civilizational experiments and provide a workable framework for shared governance on Mars, the Martian state will function as an independent planetary state and a legal peer to Earth and will later be converted to an independent state [17]. In order to better understand the challenges involved, the whole design for Dvaraka is conceptually divided into the following phases: the Pre-Initiative phase, the Settlement phase, and the Self-Sustaining phase.

3. Pre-Initiative Phase

3.1. Martian ADministration on Earth (MADE)

MADE will come into existence by 2026 when worldwide governments will join hands and the countries signing the Mars Treaty will be the investors on this project. In return, the government with the highest investment shall have the highest representation in the training program as well as MADE authorities. MADE will look after prerequisites for Dvaraka and finances, recruiting, and training of Dvarakans. MADE authorities will be selected by space organizations and national governments based on experience, managerial skills, and plan proposals for Mars. In order to have more communication among departments, MADE will have a flat hierarchy managerial structure. This is because, in a flat hierarchy, the number of proper supervision and monitoring of employees as the communication is clearer and less susceptible to degradation [18]. Another advantage of a flat hierarchical organization, at least in the initial stages, is that the decision making is decentralized and the decisions can be made faster and closer to the point of impact [19]. Since MADE will be in its earlier stages, flat hierarchy will promote innovation that will occur informally and quicker.

The authorities selected will be the board of directors for MADE. The board of directors will be responsible for managing the functionality of sub departments. Figure 1 shows managerial structure of MADE. Every mission will be under the surveillance of the Mission Control of MADE. Future goods arriving to Earth from Dvaraka will be handed over to the External Affairs department for an exchange of resources with government, private, or research sectors. The Finance Department, which will work with the External Affairs department side-by-side, will distribute money and manage budgets for the funding of missions and research projects on Mars. Human Resource Development will look after the recruitment process of MADE employees, trainee Dvarakans, and the infrastructure of MADE.

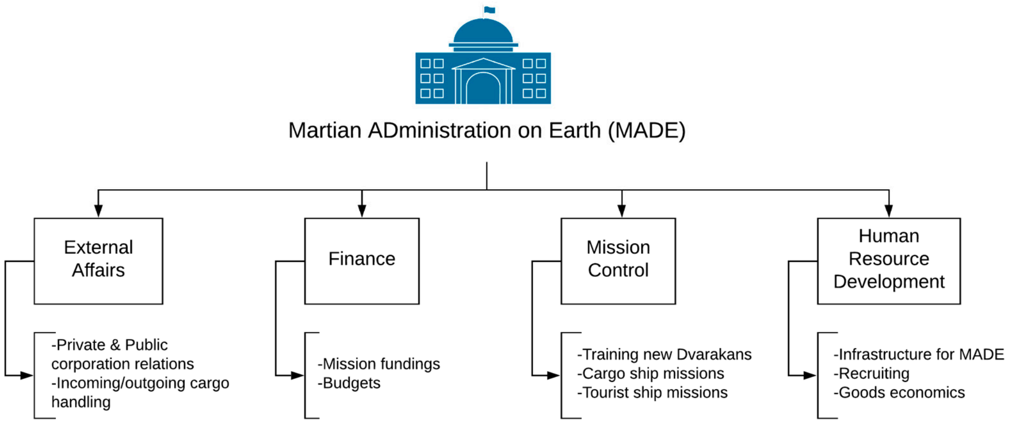


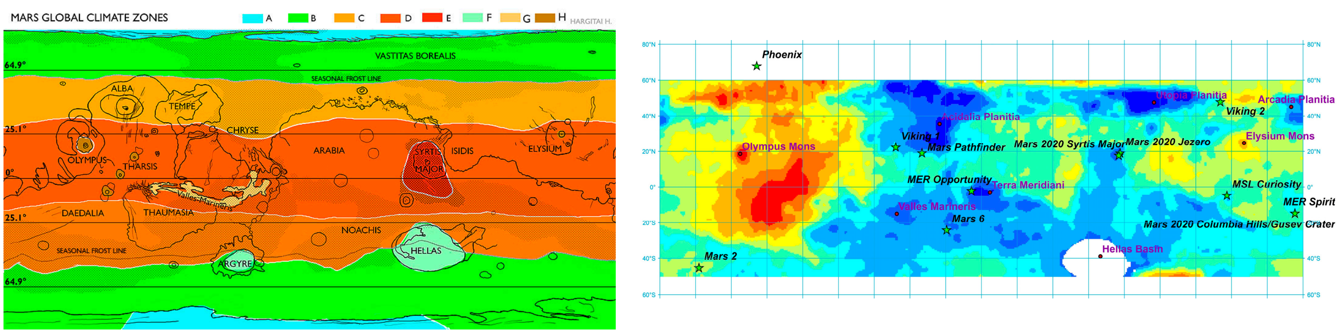
Figure 1. Martian ADministration on Earth (MADE).

3.2. Settlement Site

Landing sites and areas that might be appropriate for habitats have been suggested in a number of different locales; however, in the past, recommendations have mostly been made with the goal of establishing scientific communities or research outposts [20–22]. The strategy that was used for choosing the location of Dvaraka was to do so with the long-term objective of establishing a human community that could maintain its self-sufficiency. In order to choose the location of the colony, we employed four different degrees of criteria.

3.2.1. Site Selection Criteria

The first criterion for determining whether or not a place is appropriate involves the cultivation of plants. A map of the perfect locations displaying the various potentials for crop harvesting is one of the things that are considered. The color viewpoint is shown in Figure 2b, where blue colors represent high potentials, with the deepest blue being the best locations, and red hues represent less excellent sites, with dark red representing the worst [23].



(**a**) (**b**)

Figure 2. (**a**) Mars Global Climate Zones, (**b**) Map of the ideal landing sites on Mars from a plant perspective.

The local magnetic field for the reduction of radiation exposure is the second criterion for the identification of particular locations of interest, along with minerals for the extraction of in situ resources and scientific significance.

The third criterion to justify the acceptability of various places for habitation and under the local context is radiation protection based on the kind of habitat, possibility for future growth, and impacts from asteroids and comets.

The fourth criterion for the selection of an appropriate location is the presence of appropriate climatic conditions, which may include temperature, pressure, sunshine, water, and terrain. A map of the global climatic zones of Mars is one of the factors taken into account for this criteria [24]. A = Glacial (permanent ice cap); B = Polar (covered by frost during the winter which sublimates during the summer); C = North (mild) Transitional (Ca) and C South (extreme) Transitional (Cb); D= Tropical; E = Low albedo tropical; F = Subpolar Lowland (Basins); G = Tropical Lowland (Chasmata); H = Subtropical Highland (Mountain).

3.2.2. Proposed Settlement Site

In Figure 3a, the white star displays the position of the Jezero crater [25]. The location of the explosion is shown with a black box that has been labeled. The hillshade in the background is generated from MOLA, and the topography in the background is MOLA. Within the Jezero crater paleolake basin, Figure 3b provides a summary of the watershed regions that are responsible for the northern and western fan deposits [26]. The regions that make up watersheds are denoted by thick black outlines with descriptive labels and were obtained from the contemporary MOLA topography. Magenta denotes the networks of valleys that have been mapped. The areas of the watershed that are suggested to be crosshatched are the ones that include regions that are covered by material associated with the Hargraves impact crater. The location of the explosion is shown by a white box that is labeled, and this can be seen in Figure 3c.

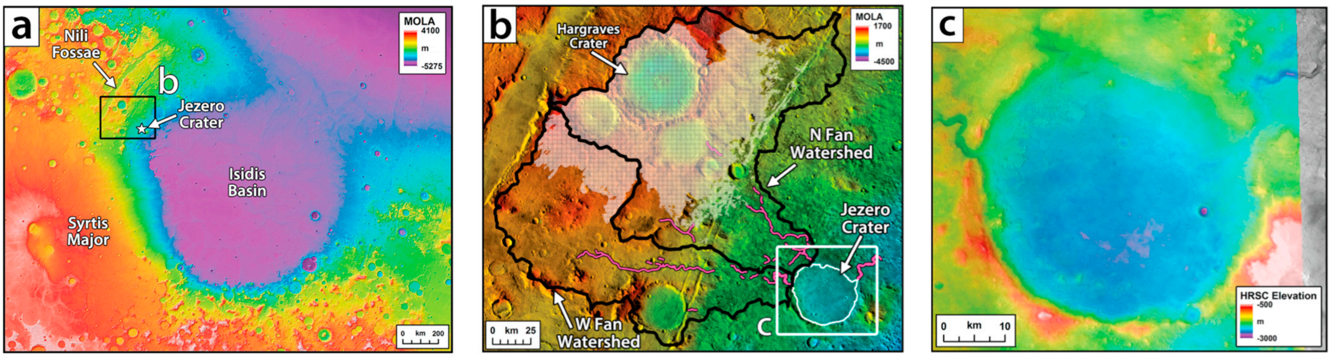


Figure 3. Proposed settlement site: Jezero crater, Mars. (**a**) the white star shows the Jezero crater, (**b**) MOLA map of the region near the Jezero crater and (**c**) is the close up imageof Jezero crater with respect to the elevation.

3.2.3. Characteristics of Selected Site

Jezero is characterized by early deltaic sediment deposition into a low salinity (i.e., habitable) paleo lake [27]. Because of its proximity to the Martian equator, this area experiences temperatures that are far higher than those seen at the planet's poles [28,29]. Moreover, there is an indication of hydrated mineral [30]. Because of the low elevation, there is a plentiful supply of water, and the potential for water to evaporate from the surface is modest. Many studies have also proved that the region is dominated by Fe/Mg-smectite to depths of at least one hundred meters [31] while the northern delta is dominated by Mg-carbonates [32,33]. It was also found that the western and the southern plains near the Jezero crater have an olivine bearing unit [34]. Apart from olivine spectral, signatures of many other igneous minerals were also observed [27]. Evidences of various other carbonate substances has also been found in the area [35]. A volcanic unit covers the majority of the basin fill, embays the eroded delta scarps, and surrounds the deltaic remains that have been separated from the main delta bodies by aeolian deflation at some point in time before to the occurrence of the volcanism. This region also contains comparatively less dust than others, providing a bit of protection from loose regolith from local dust storms, as well as providing flat ground surface for easy infrastructure development. The Jezero crater has an average local magnetic field of 0.6 A/m while the other potential landing sites such as Elysium Planitia have a magnetic field of only 0.0011 A/m [36,37]. The local magnetic field, although it is comparatively less, will help to mitigate radiation to a certain extent. The Jezero crater is one of the least asteroid-hit places on Mars, strategically making it an ideal location for a habitat [38]. Additionally, since the crater had an ancient lake along with flood deposits, it is estimated that there could have been some form of life in the past, thus additionally making it an ideal location for science experiments [39–42]. Since the crater is almost flat, building structures on it would be much easier and it will also assist in faster transportation [43].

3.3. Dawn of The Dvaraka Initiative

The year 2034 will be the dawn of The Dvaraka Initiative and by 2036, the Pre-Initiative phase will begin, followed by cargo missions from 2036. Early cargo missions will consist of hauling equipment, nuclear generators, pressurized and unpressurized rovers, and other types of carrying equipment. In the future, cargo missions carrying important raw materials, necessary robotics, and equipment for air and water facilities will be launched [44,45]. All of the cargo spacecraft will make a round journey to Mars by transporting a few tons of hydrogen from Earth and turning it into return trip propellant. This will allow them to return to Earth with their payload. After completion of the Pre-Initiative phase, Dvarakans will arrive.

Dvarakans training phase: Concurrently, a training program will be launched on Earth around the year 2038, and a selection of trainee Dvarakans will be chosen from among those trainees. Figure 4 presents an overview of the Dvarakan selection and training level arrangement. The application procedure for the chosen space firms will take place over the course of one year, and MADE will pick 250 trainees from among those applicants. Resilience, adaptability, flexibility, medical knowledge, capacity to speak English, age between 20 and 45, and a clean criminal history will be taken into consideration throughout the selection process. After this is complete, trainees will be given instructions for two weeks of a cut-off round. During this round, they will be evaluated based on their knowledge about Mars, ability to use different software, and participation in a variety of group activities. After the last phase of the cut-off process, there will be 210 trainees remaining in the group. The fundamental and advanced aspects of Martian survival will be taught to 210 new recruits each and every year. By the completion of the course, there will be 200 trainees who have successfully completed the training, and early batch graduates will be provided the opportunity to join MADE in order to get a deeper grasp of Martian government. The most fundamental activities will consist of technical, physical, and social training, respectively. Every applicant will train in a variety of abilities, and points will be granted to show their progression as they complete the training. The typical amount of time needed for an adult to establish a new routine is 66 days. Because of this, the whole of the training program has been planned out over six years.

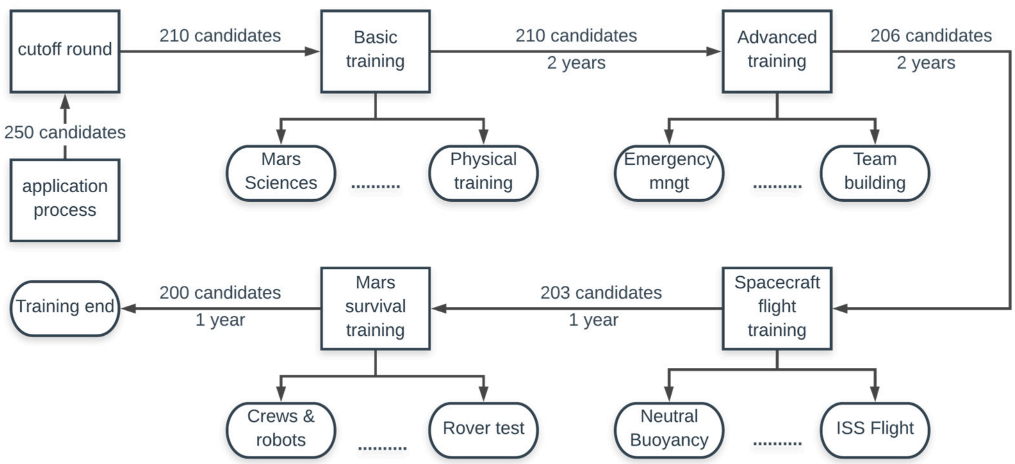


Figure 4. Training phase for Dvarakans on Earth.

4. Settlement Phase

4.1. Dvarakans Arrival

In the beginning of the Settlement phase in 2046, the first spacecraft will carry 100 people along with a food cargo for one-year sustainability, since it is not feasible to send 1000 people together. The initial spacecraft will only carry specialists in variety of fields, along with agronomists, and subsequent spacecrafts will send 100 personnel every two years. After the population reaches sixty percent, or six hundred Dvarkans, the implementation of the Martian government will begin. In the early period, representatives from each department will be in communication with MADE. The sex ratio in a population is determined by two major factors: the sex ratio at the time of birth and the disparity in death rates between the sexes at various times [46]. Although the gender ratio at birth is more favorable for boys, the gender gap in death rates favors girls, because females have a higher natural resistance to disease throughout their lives and a longer overall lifespan; females have lower mortality rates across the board even when compared to males who receive the same level of nutrition and medical care [47]. This is the case in situations in which females and males have identical access to these resources. In order to avoid an uncharacteristic sex ratio throughout the timeline of the initiative, male to female sex ratio will be 505:495. Upon the arrival, living quarters will not be in full working conditions. The first 100 people will be spending approximately 6 more months inside spacecraft on Mars surface, during which they will make houses of habitable conditions. After this, they will move into respective living quarters to start their Dvarakan life. The ultimate goal of the colonization is to terraform Mars locally in the habitat and finally, terraform mars completely. However, during the initial phases, colonization of Mars would be difficult because the temperatures, radiation exposure, and pressures are extreme. Therefore, initially, lightweight inflatable pods made out of high-precision engineered composites that are fabricated on Earth in the shape of each block are employed to mitigate the pressure differences. During the initial phases, the astronauts walking outside will be wearing a Mars suit to protect themselves from the radiation on Mars. The SHERLOC experiment that is being conducted inside the Perseverance rover will provide the data that will be needed to make the decision on the material that will be used in the suit [48]. Out of five potential materials, polycarbonate, Teflon, orthofabric, vectran, and nGIMAT coated telfon, the best performing material will be chosen to make the Mars suit [49]. However, it is to be noted that the exposure of Dvarkan to Martian atmosphere should be reduced as much as possible and limited to only emergencies. Keeping all this in mind, the Dvaraka's architectural concept is built in such a way that the colony is self-sustainable and the need for Dvarkans to venture out of the colony is limited.

4.2. Dvaraka's Architectural Concept

Throughout the process of creating the blueprints for Dvaraka, a variety of difficulties were taken into consideration, each of which had its own unique set of precedents. The findings were combined to create a new logic, and the positive parts that were drawn from each precedent were included in it. As a result, the architectural arrangement of Dvaraka that is seen in Figure 5 would become reality. Every must have some kind of long-term objective and strategy in place.

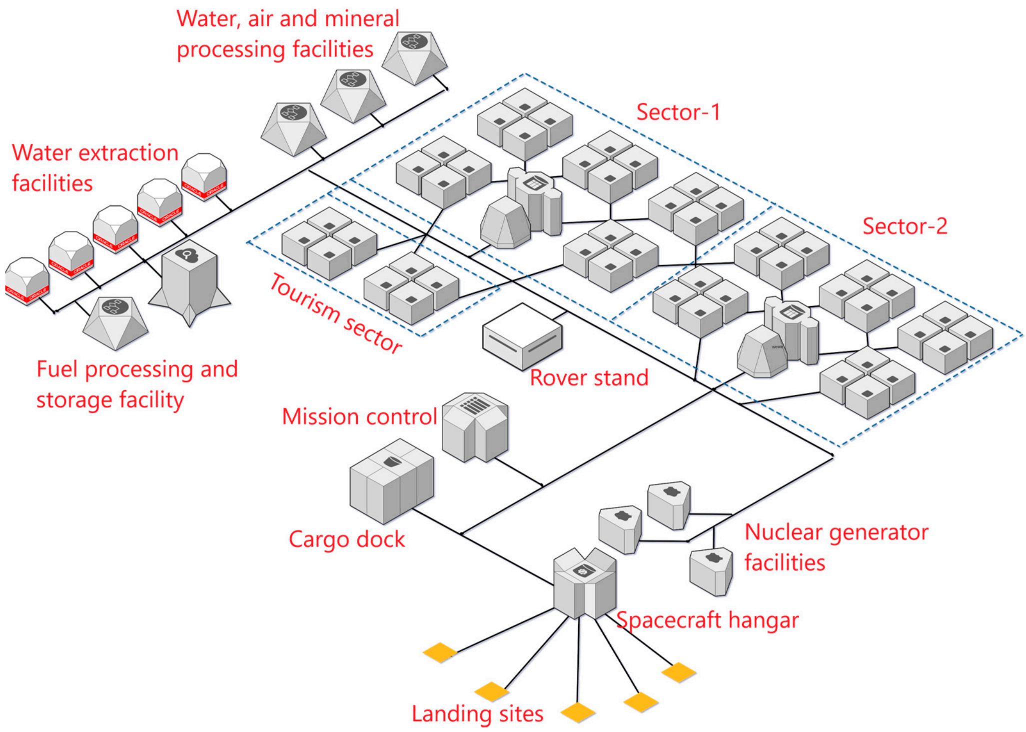


Figure 5. Dvaraka colony concept.

Safety, effectiveness, and scalability are the three most important aspects of engineering that should be considered for the design. In order to ensure safety, there must be a number of pressurized sections that are independently attached to one another. There must be a minimum of two ways out of any location in the event of an emergency, such as an unintentional loss of pressure, a fire, or another kind of breakdown. In addition, the elimination of one space shall not result in the disconnection of operational areas of Dvaraka from one another. The vast distance from Earth, along with the scarcity of both labor and energy on Mars, has a significant impact on efficiency. The pattern of development must be readily reproducible and extendable in order to meet the requirements for expandability. This must be accomplished without affecting the quality of the structures that have previously been finished. While designing the layout of Dvaraka, all three of these characteristics were taken into consideration.

The whole of Dvaraka is divided into sectors. Sector-1 and sector-2 consist of living quarters and greenhouses, while the tourism sector consists of living space for tourists. Apart from that, water, air and mineral processing facilities are established adjacent to sector-1, making it easy to distribute the primary necessities. A small hospital with all the basic requirements including latest artificial intelligence (AI) technology and biosensor capabilities will also be built [50–57]. Along the linear line of water, air, and mineral facilities, there are water extraction facilities located. Section 4.4 describes Dvarka's life support system. To reduce the space and cost required for air pollution monitoring, hyperspectral imaging (HSI) -based sensors will be used to monitor the air pollution [58,59]. A fuel processing and storage facility is built opposite this. Far in the distance on other side and connected to sector-2, mission control is established near landing sites, along which a cargo dock is built, making it comfortable to load and unload cargo on spacecraft. In same area, nuclear generator facilities are operating with the main aim of providing power to all of Dvaraka. A special area, the rover stand, has been allocated beside the tourism sector, and this is where Martian Land Vehicles (MLV) can be built and repaired [60].

Sector layout: Figure 6 shows the top view and isometric view of conceptual layout of sector section of Dvaraka. Each sector includes five blocks and one administration building. Each block consists of 100 living quarters. Each living quarter will be assigned to 1 person so making 100 people in one block, totaling 500 people in one sector. Since Dvaraka has two sectors, it can occupy 1000 people in total. The administration building consists of facilities for administration offices, entertainment, sports-halls, and other activities. Each sector is a square ∼500 m on a side, making it a reasonable distance for Dvarakans to walk. Dvaraka also comprises of tourist sector, which includes two blocks, providing a capacity to host 200 tourists at a time.

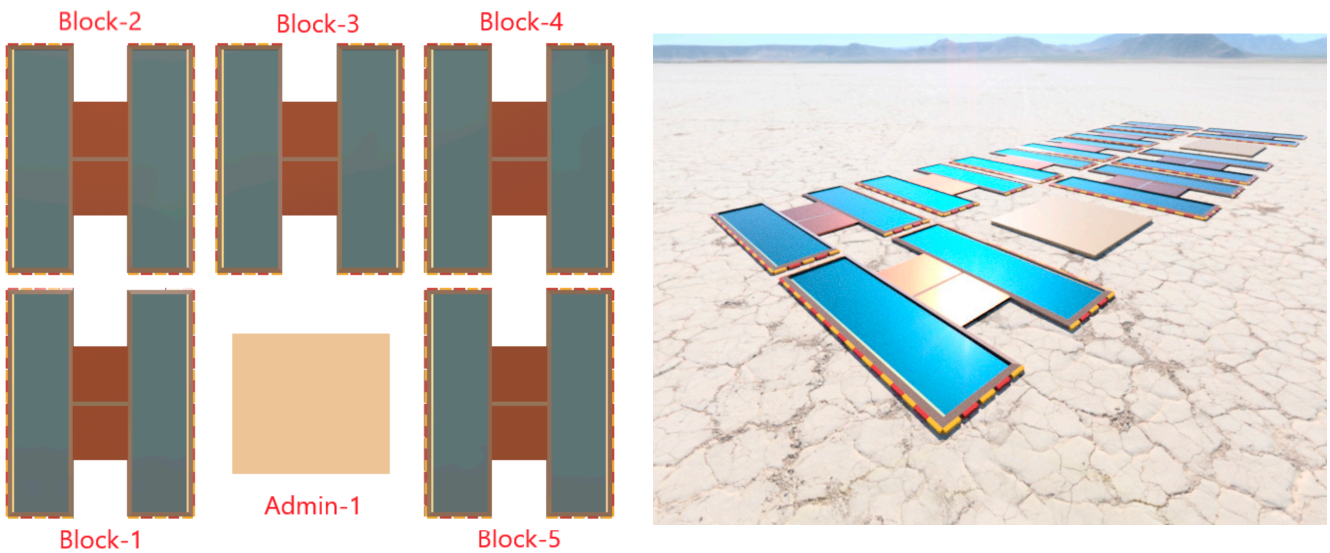


Figure 6. Dvaraka's sector concept.

Block layout: Each block covers an area of 31,488 m^2. Figure 7 shows a block cross-sectionally viewed from the top side. It consists of two greenhouses, one hundred living quarters, one dining hall, and one laboratory for conducting a variety of research experiments. If an individual is content to consume nothing but wheat, then an area of plant growth of just around 15 square meters is all that is necessary to provide them with the nourishment they need. If an individual also wants to grow other things, then 50 square meters should be plenty. Martian soil is less fertile than Earth's soil and hence by adding safety factor of 4200 m^2, this should be sufficient for one person. For 100 people in a block, a 20,000 m^2 plant growth area would be required. Each greenhouse of 50 m $\times$ 200 m covers an area of 10,000 m^2. With two greenhouses, the block has the capability of providing enough food for 100 people. The dining hall and laboratory are of same size, 50 m $\times$ 50 m, covering an area of 2500 m^2. There is a passage which is 4 m wide and 4 m high which provides a common connection to reach any part of the block.

Living quarter: The layout of each living quarter is shown in Figure 8. The size of one living quarter is 2 m $\times$ 10 m, providing a comfortable living space of 20 m^2 per person. The height of the wall facing outside is 2.2 m, while the wall facing towards passage is 2.75 m. According to the requirement, it is possible to convert two single living quarters into one double living quarter. Outer living quarters will be provided with windows, while inner living quarters will have transparent roofs, along with a shades mechanism to enjoy sunlight or a night sky view whenever required.

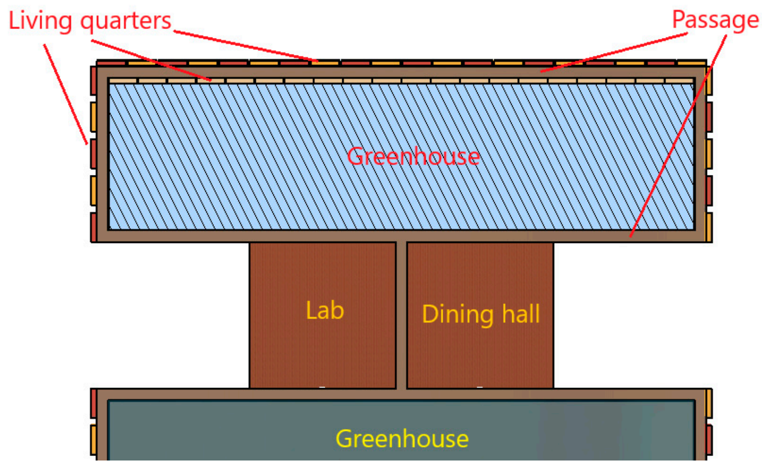


Figure 7. Block's cross-sectional view (from top).

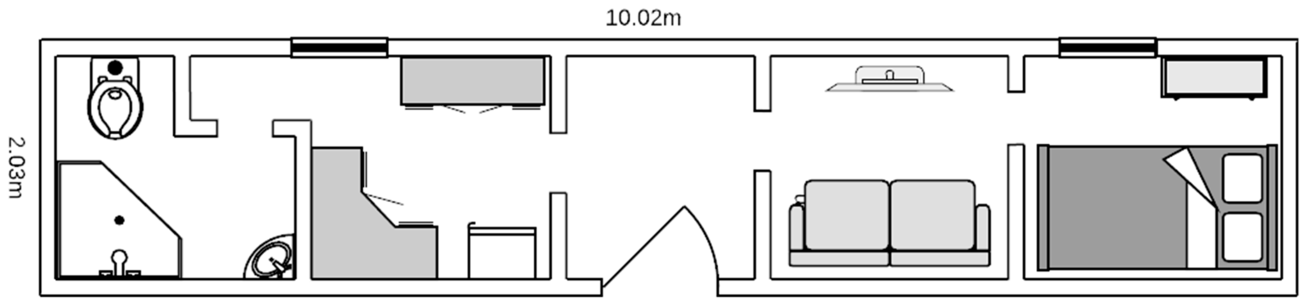


Figure 8. Living quarter's layout.

4.3. Infrastructure Materials

Sending materials for building structure from Earth is not an economically practical idea. There are high concentrations of oxides of iron, silicon, magnesium, and aluminum in the regolith of Mars [61]. It is conceivable, according to the research and invention that has been done in the field of material science, to get the needed materials for constructing infrastructure on Mars by employing a variety of various synthesis procedures. Due to the high concentration of carbon dioxide in Mars' atmosphere, it is theoretically possible to manufacture various plastics there, such as polyethylene, polypropylene, and polycarbonate [62]. For the main infrastructure of Dvaraka, bricks and sulfur- based concrete is proposed to be used, along with thermomechanical coating (TMC), which can be extracted from Mars regolith [63]. The outside walls will have a thickness of 65 mm, of which 50 mm will be the thickness of the brick, and the remainder will be TMC. Figure 9 shows the arrangement for the outer wall, along with configuration of TMC. TMC protects against extreme cold temperatures, impact, fire, heat, wear, abrasion, chemical degradation, thermal conduction, and radiation heat losses. Moreover, it is flexible enough to allow for simple and reproducible folding and unfolding. In the regolith part, a thickness of 50 mm was chosen based on the analysis done through Autodesk's CFD simulations. Analyses of different thickness of 10 mm, 20 mm, and 30 mm were conducted to check the structure's integrity to handle to temperature difference, pressure difference, and the dust storm. In the simulations, it was observed that 30 mm was stable and with a factor of safety of 40%, 50 mm was chosen. As for the 15 mm of the TMC, this was chosen based on the heat loss required for the colony. If the thickness is increased or decreased by 5 mm, the heat loss will not match the exact requirement for the colony. The percentage of the different materials in the TMC was also chosen based on the proportions of available materials found on Mars.

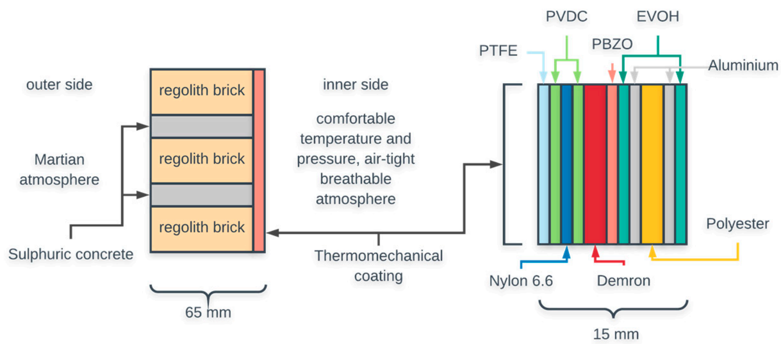


Figure 9. Material for outer wall.

Thus, TMC is in charge of creating a sealed environment that enables the human life, maintaining the pressure and breathable atmosphere in addition to the needed structural resistance to withstand the difference of pressure between the environment, the interior, and the possible impacts. For the roofs of greenhouse and inner living quarters, polymethyl methacrylate (PMMA) will be used. PMMA glass is transparent thermoplastic material which is perfectly suitable. The raw materials used for making PMMA glass are available in Martian regolith and can be extracted and synthesized to make PMMA glass on Mars. In addition, PMMA glass offers protection against UV radiation with a wavelength of around 300 nm, which is within the normal range for Mars's atmosphere. Ethylene, in addition to being utilized in the production of fundamental materials, may also be employed in the production of thermoplastic elastomers, which are the principal material used in the production of space suits. In addition to carbon, nickel, manganese, aluminum, and steel, other metals are necessary for the production of colony usage equipment and are also able to be recovered and processed [36,64–67].

4.4. Dvaraka's Life Support System

The schematic of Dvaraka's life support system (DLSS) for potable water production, breathable air production and propellant production system is shown in Figure 10. A Sabatier reactor receives carbon dioxide from the atmosphere and hydrogen that has been electrolyzed from ground water in order to create oxygen and methane [68,69]. The Sabatier reactor produces oxygen and methane at a ratio of 4:1 [70]. Since this is more than the ratio that the engine is supposed to have, it will create too much oxygen. As a consequence, the generation of methane serves as the primary objective of DLSS. Taking into consideration the average daily consumption of 9.6 kg of water and 2.8 kg of oxygen by individuals including tourists, 11,520 kg of water will be needed for 1200 people every day, while 3360 kg of total oxygen will be required for the same number of people [71,72]. In light of the fact that the DLSS water extraction subsystem will have the capacity to extract 68.2 kg/h, 16 facilities will generate a total of 26,188 kg/day. Electrolysis generates 23,372 kg per days' worth of oxygen, of which 20,341 kg per day are used for the production of propellant, and the remainder 3032 kg per day are sent to an air processing facility. The electrolysis process results in the production of 5812 kg/day of methane, which will be utilized for the manufacturing of propellant, as well as 13,051 kg/day of water, which is transported to the water processing plant. The quantity of hydrogen that is supplied to the Sabatier reactor is 2922 kg/day. As a result, 9.54×106 kg/year of propellant is generated, which is sufficient to meet the requirements of all spacecrafts, both incoming and outgoing. Figure 11 illustrates the many routes that air capable of human respiration may go inside Dvaraka. In the air processing factory, pure oxygen will be converted into an air ratio that is suitable for breathing. The living quarters, the kitchen, and the laboratories will all receive this oxygen-rich air. This air, which has a higher carbon dioxide concentration, will be sent to greenhouse chambers after being released from the aforementioned places. Using a process called photosynthesis, the plants that are grown in greenhouses will create oxygen. This air, which has a higher percentage of oxygen, will be fed into the facility that processes air.

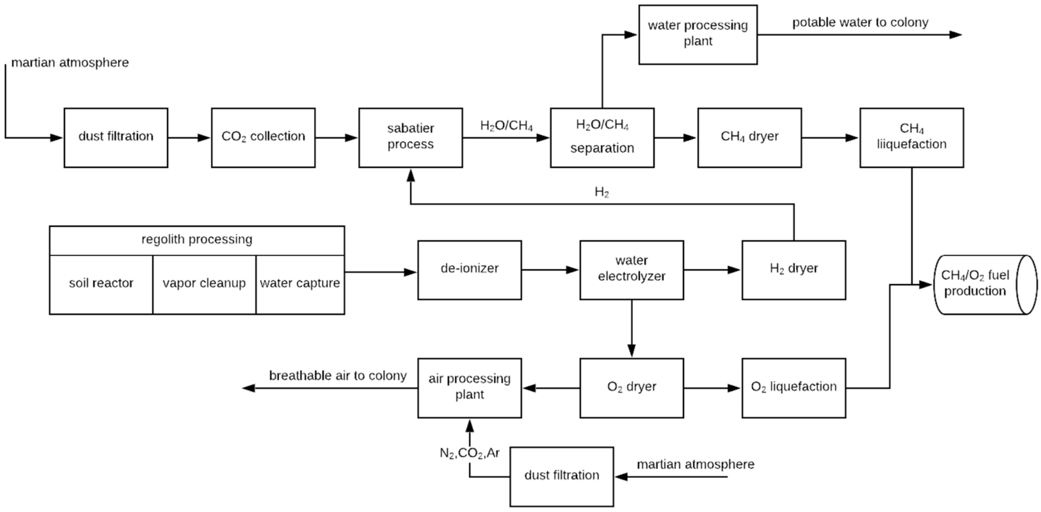


Figure 10. Dvaraka's life support system.

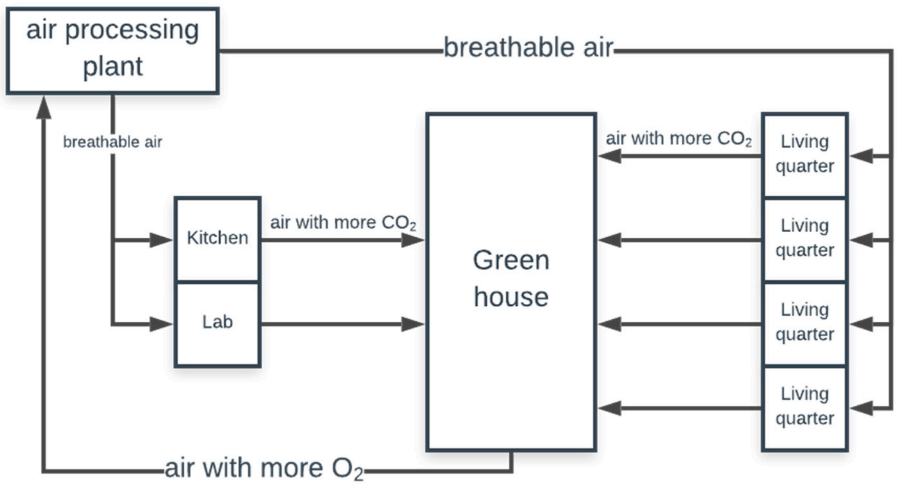


Figure 11. Breathable air circulation system.

4.5. Food Production and Waste Management

Each block consists of two greenhouses, which can provide adequate nutrition to 100 Dvarakans. The greenhouse will be serving the need of food and oxygen for 100 people. Every day, a healthy body needs two kilograms of food in order to acquire the nourishment and energy it needs. Within these 2 kg, the intake of essential nutrients needed is 56 g of protein, 400 micrograms of folic acid, and 1000 milligrams of calcium [73]. However, for iron quantity, it is double the amount for females, and vitamins intake varies with each person [74]. In a scenario where a person is pregnant, intake doubles. In order to fulfill these values, different crops are selected to be grown based on their growth conditions and nutrition values. Therefore, there is a selection of crops: poppy seeds, winged and soya beans, lentils, potatoes, tomatoes, onions, green beans, spinach, beets, oranges, and lemons. All these crops require approximately 6–7 h of sunlight and 12–14 h of artificial light, manures, and a proper drainage system [75]. The only kind of watering that these plants need is an occasional misting. It is necessary for the soil to have a high concentration of the nutrient's potassium, phosphorus, and nitrogen. To improve the quality of the soil, composites, lime, and sulfur will be added in the appropriate amounts to keep the pH balance appropriate for the crops being grown. In order to create nitrogenous soil that is rich in rhizobium, bacteria will be employed [76]. During the first two years of the mission, one hundred kilograms of manure will be sent from Earth at a cost of one thousand dollars per ton, and at the same time, the Martian soil will be prepared. Perchlorate is excess in Martian soil, which can be reduced by adding gypsum [77], and this will be used to calculate the exact amount of gypsum required to reduce the perchlorate FREZCHEM used [78]. Some dry fruits and egg and milk powder will also be needed to import. During this time, fertilizers will be getting ready in the recycle plant, as shown in Figure 12. Every lavatory will be connected to a plot where waste products will be collected in separate tanks. Water waste will go through a urine filtration process, which will separate 75% of water and 5% of other nutrients such as nitrogen, phosphorous, and potassium. The solid waste products will be sent for the decomposition process. The nutrients from filtration process additional nutrients mixed with animal manure and sewage sludge to increase the process of decomposition. Manure takes 6 months to be prepared, after which it will be sent to greenhouse along with water for the cultivation of crops.

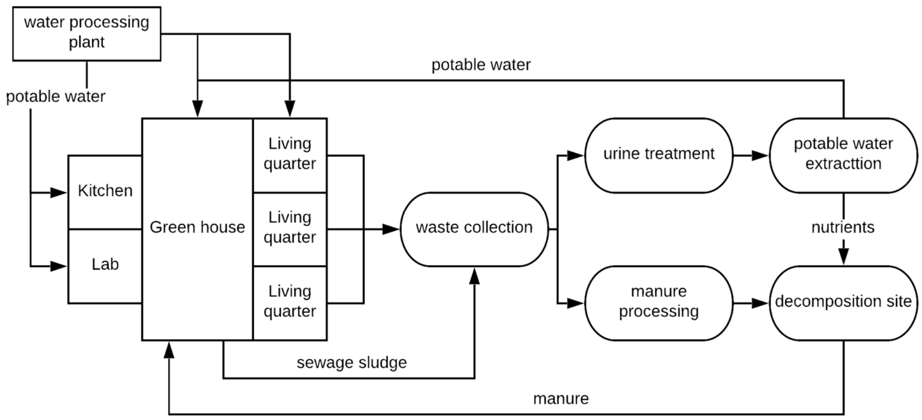


Figure 12. Layout of manure and water recycle plant.

4.6. Electricity Production

In Dvaraka, the electricity that is needed could well be caused by the following functions: air conditioning of houses, household appliances, research and office supplies, processing facilities (water, air, and propellant), production of basic materials, water extraction facilities, and agricultural productions. In other words, the demand for electricity will be driven by a wide variety of activities. It is estimated that the need for electric power is 3.5 kWe per person (4.2 MWe for 1200 people), leaving the lighting of greenhouses out of the calculation. Taking into consideration the various factors, such as the scale effect, the possibility of providing some of the needs in thermomic mode, and the conservative assumption regarding the consumption of commercial activities, it is possible to arrive at this estimate. Considering an average power usage of 17 kWe for each processing facility, with these numbers, the total power need reaches about 6.1 megawatts of electricity. Adding 58.3 kWe of power use per greenhouse, the production and distribution of electrical power will be accomplished by a mix of nuclear reactors powered by uranium and at least one system of nickel-hydrogen batteries [79]. For example, dust storms may persist for a few weeks, as well as the successive duration of excavating through the generated sands, which can take a significant amount of time. Suitable nuclear reactor implementations will be independent of environmental conditions, and as a result, they will provide reliable energy for even the harshest of circumstances. At the moment, it is thought that the baseline reactor will develop into an improved version of NASA's Kilopower Reactor [80,81]. From a design with a maximum output of 10 kWe, the evolution will produce a reactor with a capacity of 100 kWe, bringing the total output to 100 kWe. The total amount of electricity produced is 3 MWe, and there are 30 nuclear reactors. The production of nuclear electricity is not the only option available. Solar panels are going to be installed on the roof sides of the outer living quarters, pas-sage, laboratory, and kitchen facilities. At an efficiency of 33% and taking into account 100 watts per square meter, the amount of solar power produced will be 4.16 megawatts of electricity (MWe). The area that will be covered by solar arrays on 12 blocks of buildings will be 126.336 m^2. Hence, the overall power production will amount to 7.16 MWe, which will be sufficient to meet Dvaraka's complete need for energy. During the dust storms, the solar arrays will be covered with a layer of dust and these storms last for few weeks to few months. To meet 6.1 MWe, we have nickel-hydrogen batteries which will be charged from part of excess power 1.06 MWe that we are generating from nuclear reactor during a Martian day when the weather is clear and there is no dust storm. Each living quarter will be equipped with a nickel-hydrogen battery that will work independently of scenarios such as a dust storm. Additionally, wind energy could also harvested in the future [82].

4.7. Thermal Design

Assuming the thermal output at 95% efficiency from 30 nuclear generators, along with the electric power we are getting thermal output of 9.417 million btu per hour which puts us at 226.01 million btu per day. Jezero Crater's average temperature is 227.45 K (−50 °F) and the greenhouse runs at 299.8 K (80 °F), so the temperature difference δT is 72.35 K (130 °F) [83,84]. The total exposed area of one block is 60,000 m^2. This exposed area includes bottom, top, and sides, which are directly in contact with either mars land or mars atmosphere. Dvaraka infrastructure is made of bricks and concrete and the walls are covered with TMC which has total thermal resistance (R) value of 11.5. Thermal resistance is well-defined as the proportion of the temperature variance between the ends of TMC and the amount of heat drift over an unit area [85]. It was calculated from Equation (1) where R_θ is the thermal resistance, Δx is the temperature difference, A is thickness, and K is thermal conductivity.

$$R_\theta = \frac{\Delta x}{Ak} \tag{1}$$

The total heat loss with reference to the above area is 195.32 million btu per day. It was calculated by multiplying thermal output multiplied by the resistance. A factor of safety of 2.5% was also considered. This heat loss value is total heat loss calculated including every infrastructure building of Dvaraka. During the dust storms, the average temperature difference in 314.2 K (106 °F) [86]. Hence, the total heat loss during the dust storm was 159.27 million btu per day. A better way to interpret this information is, 195.32 million btu is heat lost from Dvarka, and to keep it warm, we are continuously supplying 195.32 million btu from 226.01 million btu thermal output. The difference between thermal output from nuclear generators and the heat loss is 30.69 million btu which will be supplied to keep the other facilities in Dvaraka, for example mission control, water/fuel extraction building, bricks and cement manufacturing machinery, etc. The air heat rejection mechanism will be used for the initial installation of the first few reactors. When the Dvarkans have arrived, the Dvarkans will mount the reactors and employ a more robust system of cooling by putting the heat rejection pipe system to Dvaraka, in order to make up for the heat loss that will occur throughout the installation process.

4.8. Against All Odds of Dust Storm

Martian winds can frequently generate large dust storms [87,88]. While Mars is at its perihelion, the planet's southern hemisphere experiences an abrupt increase in temperature, which results in a significant temperature disparity between the planet's northern and southern hemispheres. As a result, strong winds and dust are propelled from the southern to the northern hemisphere. The majority of the storms travel at speeds ranging from 14 m per second to 32 m per second and disintegrate in a matter of days [89]. An experiment is simulated in a wind tunnel performing dust storm scenario with a wind speed of 50 m/s. Taking into consideration curves and contours of design, 2D analysis is done for the scenario mentioned, which is shown in Figure 13.

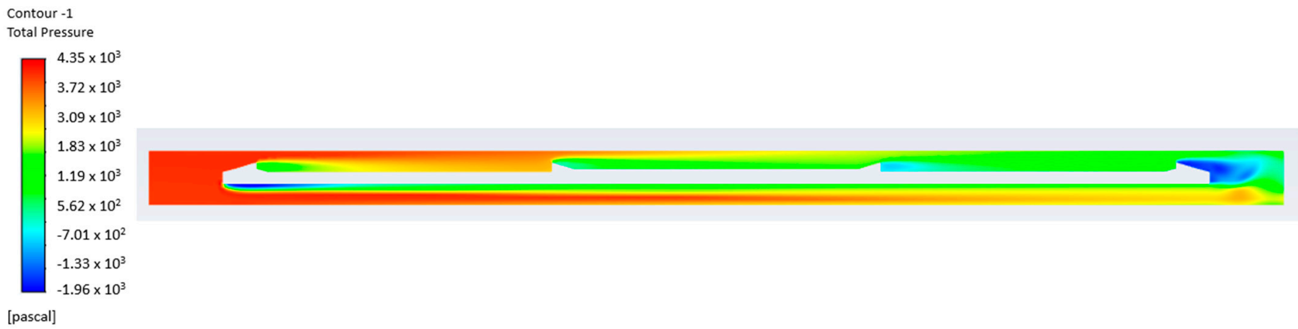


Figure 13. 2D analysis of cross-section of Dvaraka's block design.

Additionally, 3D flow analysis is done on Dvaraka's block building which will hold living quarters for Dvarakans. The same scenario is performed in 2D, but with three different orientations of blocks with respect to the direction of wind. Results obtained are almost the same, stating maximum surface pressure of 4350 pa. Figure 14 shows two other orientations, resulting in range of ~1300–2400 pa surface pressure. Thus, structural and thermal analysis is performed on living quarters with respect to 5000 pa surface pressure, considering the maximum obtained value of surface pressure.

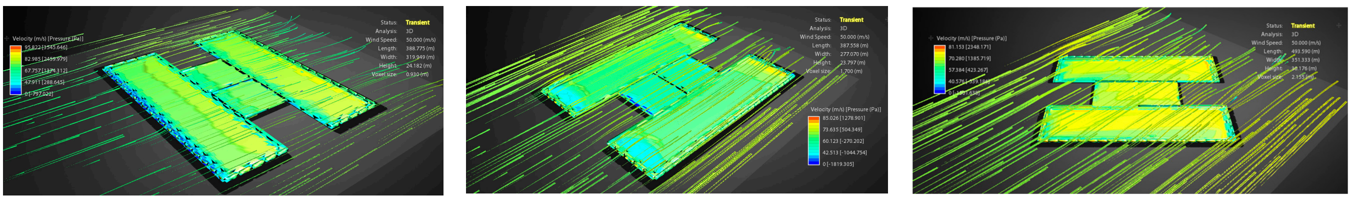


Figure 14. 3D flow analysis of Dvaraka's block design.

Figure 15a shows structural analysis, displaying a displacement graph with a maximum value of 22.07 mm. Figure 15b shows thermal analysis, stating heat flux with maximum value of 168.9 W/m^2 on edges of living quarters. From structural and thermal analysis, it is concluded that Dvaraka's infrastructure is able to withstand the thermal displacement caused by pressure and temperature difference in case of a dust storm. The inside pressure and temperature are constantly maintained, and the outside conditions vary from time to time. The infrastructure is designed in such a way that it withstands all the odds of the dust storm and Martian temperature changes with a factor of safety (FOS) of more than 2. The factor of safety was considered based on the maximum pressure the structure needs to withstand divided by the average actual pressure. Wind speed was also taken into consideration while calculating the FOS where more than twice the average wind speed has been considered for simulation.

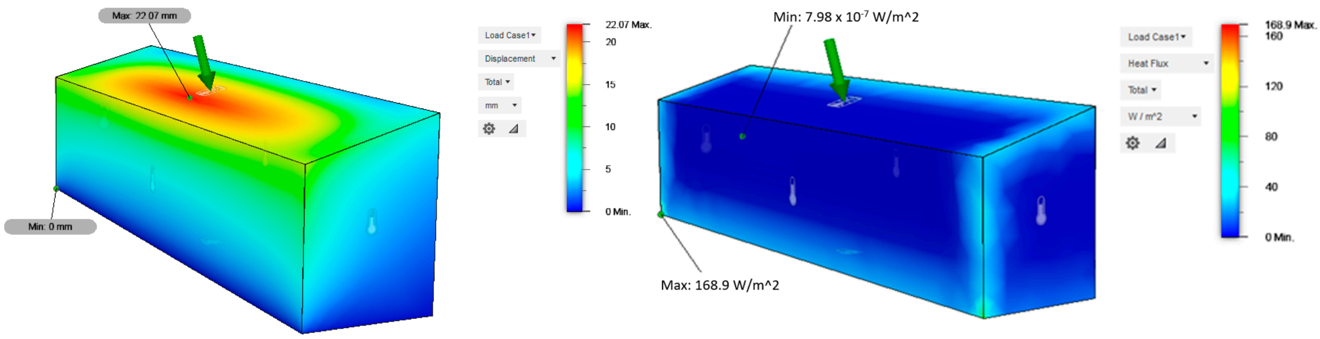


Figure 15. Thermal analysis of Dvarka's living quarter.

The driving parameter for the simulation is wind speed, keeping in mind that the worst dust storm scenario with 50 m/s wind speed was taken into consideration. Firstly, a cross sectional area of colony structure was simulated in 2D wind tunnel with 50 m/s to obtain a maximum pressure generated on the outer side wall. The same scenario was also simulated with a 3D model to cross check the results obtain from 2D simulation. Both results show approximately 4350 pa pressure on the outer side of the wall. Since living quarters are allocated on the outer rim of the colony structure, they are going to be affected the most. Therefore, the living quarters' outer wall needs to withstand 4350 pascals (obtained from wind simulation), hence a scenario for living quarters was simulated, where the outer wall faces 5000 PA. The results obtained shows that with 50 mm brick foundation, the structure can easily withstand the pressure applied.

5. Self-Sustaining Phase

5.1. Economic System

The Dvaraka Initiative is a model of a new economy to introduce a trade system on Mars inspired by a similar pattern on Earth for several years. The reason for the same is to create a self-sustainable version of human life on another planet. Our experiences on Earth give us enough perspective to judge the influence of the suggested economic system on Dvaraka. The primary objective here is to identify the feasibility of the project which comprises several stages of analysis beginning with the initial investment on the basis of which Dvaraka would be erected, following the initiation of the settlement. As the initial investment is made on Earth, all financial transactions related to the project, including cash inflow and outflow as well as consumables used in the construction of Dvaraka, will be calculated in US dollars. The cost of transporting commodities from Earth to Mars, which is listed at USD 500 per kilogram, and from Mars to Earth, which is marked at USD 200 per kilogram, is one of the limitations of the case. This constraint helps us design an economic structure for the profitable operation of Dvaraka in the long run. The economic analysis can hence be commenced with these constraints.

5.1.1. Initial Investment

Generation of First Investment: The foundation stage of Dvaraka will be laid by investments from across numerous government entities on Earth. This will be the initial stage of investment generation. The sequence in which various government agencies participate in the first investment will have an impact on the way business is conducted in Dvarakan. The investors will provide a loan of USD 5 billion every two years, which will be automatically taken from them. Additionally, the funds that are created for training will be added to the starting account, which is now worth USD 3.15 billion. Because of this, the preliminary expenditure for the project is USD 65 billion.

Flow During the Pre-Initiative Phase: The Pre-Initiative phase will consist of five missions, each of which will include the conveyance of various resources, including equipment, raw materials, and other essential components. It is reasonable to assume that each mission will have a cost of around one billion dollars. In addition to this, it makes use of the equipment that is carried to Mars, which may include heavy machinery, raw materials, or rovers in order to construct the fundamental components of Dvaraka in advance of the arrival of Dvarakans.

The outflow that occurs during the Settlement Phase: The Settlement phase consists of six different missions. The first shipment of Dvarakans will include cargo consisting of food and different utilities, which will cost a total of USD 700 million. The transportation expenses for the next five missions, each of which will comprise of 200 Dvarakans plus cargo, will be close to one billion dollars. These figures are approximations, with the weight distribution being taken into consideration.

5.1.2. Profitable Operation

This plan for the economy of Dvaraka discusses a variety of businesses and estimates the revenue that can be expected from those businesses once they are operational in a fully developed settlement. The goal of this plan is to ensure that the economy of Dvaraka is able to maintain its own self-sufficiency. The following is a list of the possible means of nutrition that might be used on Mars:

Tourism: Four schemes for tourism are proposed based on duration of stay, amount of propellant used, and frequency of travel in a year. The aim behind having numerous structures is to amplify the regularity of voyages to Mars. The amount of fuel expended for the different trajectories possible around the year determines the ticket prices. Hence, the four schemes, A through D, are specified in order of the time spent by the people in Mars. More fuel for a lesser number of days demands a higher ticket cost as can be referred from Table 1 (see Supplementary Material Tables S5–S8 for detailed calculation).

Table 1. Revenue generated from Tourism.

Scheme	Total Duration	Frequency (1 Year)	Cost/Tourist	Ticket/Tourist	Total Revenue (1 Year)
A	95 days	4	$5,135,463	$19 million	$5.5 billion
B	160 days	4	$8,824,496	$16 million	$2.87 billion
C	320 days	4	$9434	$13 million	$2.85 billion
D	450 days	4	$6,926,119	$10 million	$1.23 billion
		Total Revenue generated in a year ($)			$12.5 billion

Deuterium Generation: Deuterium, the heavy isotope of hydrogen, has a composition of 166 parts per million (ppm) on Earth, but 833 parts per million (ppm) on Mars [90,91]. On Earth, fusion reactors of the first and second generation both rely heavily on deuterium as their primary source of fuel [92]. On this planet, the price of 1 kg of deuterium ranges anywhere from USD10,000 to USD 16,000, depending on how pure it is. Hence, the expected profit per kilogram is somewhere near USD 9500, and this is the case even if the price falls as a result of decreased demand. The expected profit for one ton is USD 9.5 million. The creation of 1500 megawatts take 400 kg of deuterium every day, and there are now 452 nuclear power plants in operation or in the process of being constructed throughout the planet. It may be deduced from the data shown in Table 2 after the calculations are completed. Each year, there is a need for 8 tons of deuterium. The profitability of carrying 90 tons of deuterium once every two years is calculated to be USD 746.58 million.

Table 2. Revenue from Deuterium exports.

Total D Exported from Mars	87,989.33 kg
Transportation costs	$133.32 million
Cost of D on Earth	$10,000
Total cost of D on Earth	$879.89 million
Total Revenue generated in 2 years	$746.58 million

Asteroid Mining: Asteroids near Mars provide us with an abundant source of metals which are rich in quality [93,94]. Our expeditions to some of these element rich asteroids shall start from 2052. We are able to evaluate the potential earnings that may be made through asteroid mining with the assistance of asteroids such as Aspacia and Rudra. We used the mass ratio of Ceres because it is further away from the asteroids we are studying than any of the other asteroids. This is because the mass ratios that are used in the calculation of the amount of fuel used in asteroid mining have not yet been determined for any of the individual asteroids. It is anticipated that the entire cargo from the asteroid will be 7500 tons, and that it will be possible to remove it with a success rate of 75%. The rocket can carry a payload of 85 tons on each of its journeys, bringing the total quantity of cargo it transports in a year to 233.75 tons. Table 3 displays the revenue that was made as a result of asteroid mining. Considering that platinum makes up 25% of the weight of the asteroid's ore that was extracted, the remaining ore is rich in other elements that may be put to use on Dvaraka for a variety of applications. These elements include nickel, iron, copper, and others.

Table 3. Revenue from Asteroid Mining.

Platinum Extracted	233.75 Tons
Cost of Platinum on Earth	$26,500 per kg
Cost of Transport per year	$386.37 million
Estimated cost of payload from asteroid in a year	$6.19 billion
Total Revenue generated in a year	$5.81 billion

Broadcasting: On Earth, the patterns of broadcasting for events of the magnitude of the moon landings, the events of the Olympics, and the launches of the ISS were studied, and a pattern for the broadcasting of events such as the landings of tourists and settlement dwellers on Mars and asteroid mining was designed [95,96]. The revenue was generated as is seen in Table 4.

Table 4. Revenue from Broadcasting.

Arrival of New Dvarakans	5
Tourism (in 6 yrs)	66
Asteroid Mining (in 6 yrs)	4
Total events broadcasted in first 6 yrs	75
Revenue generated per event (state of the art)	$183 million
Revenue generated in 6 yrs	$13.75 billion

5.1.3. Cost Plan

Figure 16, which depicts the different enterprises over the course of 25 years, is investigated and evaluated in order to anticipate the time at which Dvaraka will be able to support itself on its own. The flow of costs is mapped out depending on the timetable of the project, taking into account both required endeavors and those that are introduced to generate profits.

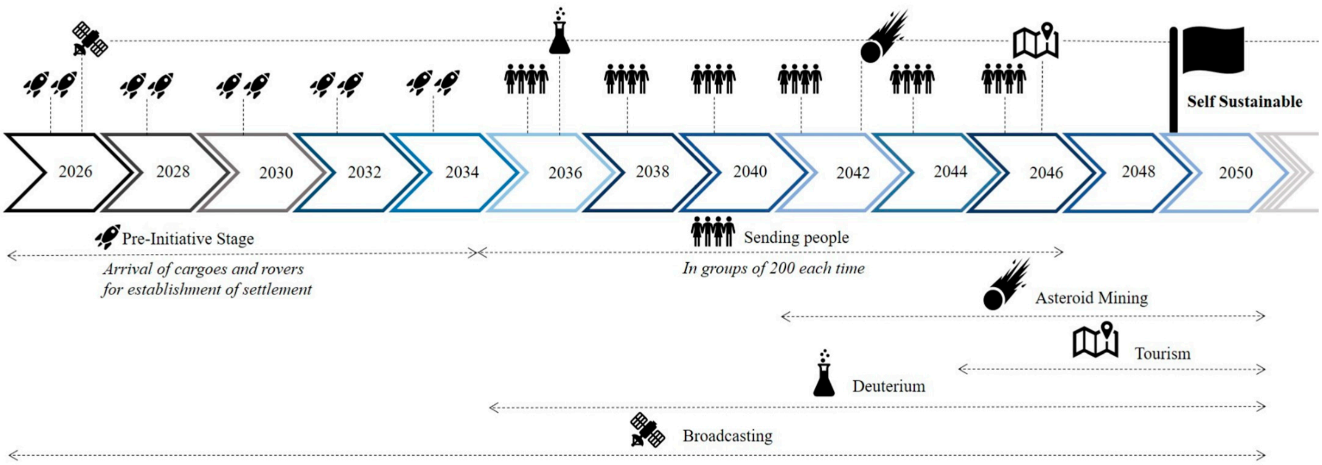


Figure 16. Timeline for the order of events in the making of the Settlement.

The yearly expenditure and income of the Dvaraka initiative can been seen in Supplementary Material Table S3. The yearly planned average until the complete setup of Dvaraka can be studied as per the different phases we have divided the project in the Pre-Initiative phase, the Settlement phase and the full sprung Self-Sustaining phase. All three of these phases comprise the initiation of our profitable operation, which makes it possible for us to see the economic trend of our project.

2034- Formation of MADE, Spacecraft manufacturing (2036 onward).

2036–2045 MADE operations, multiple cargo missions, Broadcasting events, Training of Dvarakans.

2046–2055 Cargo and Manned missions, Mining on Mars-Deuterium, Broadcasting events, Asteroid mining mission (2052 onward), Tourism (2056 onward).

2056–2060 Rounded functioning of profitable operations.

2060–2061 Payment of debt (initial investment), Self-Sustainable Settlement.

It is clear that the venture begins making profits from year 2056 onward, however the debt for the project is repaid in year 2060, keeping in mind the smooth operation of the profitable events. This credit further revenue generated directly into the future development of Dvaraka and the future settlements. Using the data from the cost plan, the graph in Figure 17 is plotted (see Supplementary Material Table S10 for complete cost plan analysis). We see the cumulative patterns of cost inflow, cost outflow, yearly investment and total revenue generated over a period of 32 years. The revenue curve defines the strength of the economic plan of the project. The nature of the revenue curve is as explained below:

1. Gradual Increase until 2054: Pre-Initiative phase and development of the project.
2. Steep Increase until 2059: revenue generated from tourism and asteroid mining.
3. Steep reduction in 2060: repayment of the initial investment
4. Increase in revenue after 2060: profitable ventures in a fully functioning society

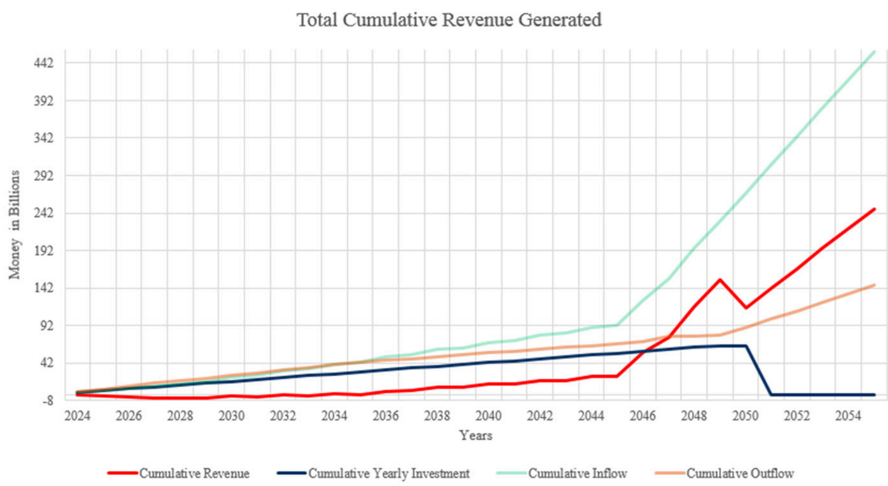


Figure 17. Economic Projection of the Dvarakan Settlement (2034–2065).

Hence, the graph concludes that the ventures (listed above) in the economic plan hold viable upon the installation in a fully functioning settlement.

5.1.4. Economic Viability and Future Scope

As is concluded from our analysis of the project, 2060 shall be the year Dvaraka becomes a self-sustaining society, having paid all their debt. This shows that the following economy plan is viable since it promises sustenance in less than 25 years. The project is well-rounded since it is symbiotic with the future developments that make Dvaraka progress. In the future, Dvaraka's economic independence from its contemporaries on Earth allow for MADE to govern as an independent body of its own. MADE shall become the Martian embassy on Earth comprising official representatives among those fifty people who do not make through the training program. Eventually, TDC on Mars will be formed into a Martian government responsible for all political, social, and economic operations on Mars. This enables the newly formed Martian Government to build more Martian colonies from the revenue generated through the profitable operations discussed above.

Dvaraka has the potential to serve in the future as a refueling station for interplanetary expeditions such as the Human Outer Planet Expedition (HOPE) [97,98]. For research on Earth, Dvaraka shall work in providing samples retrievable from Mars which will be priced as per the distance from Dvaraka, time, and fuel required for the transport of the same. The same could not be estimated in our current plan due to the deficit of information. A significant contributor to the growth of the Martian economy will be its participation in the advancement of biomedical research. This will be possible primarily as a result of the wide range of atmospheric conditions that exist on Mars, which makes it possible to cultivate and treat specific microbes that cannot be found on Earth. The study on semi-conductive materials, which needs circumstances similar to a high vacuum and is thus unavailable on Earth, can possibly to be smoothly managed on Mars. This ground-breaking research would not only provide for Earthly consumption but also for future Martian developments.

5.2. Social and Political Model

5.2.1. The Dvaraka Council (TDC)

To enable new human civilizational experiments and provide a workable framework for shared governance on Mars, the Martian state will function as an independent planetary state and a legal peer to Earth, while later when the total population reaches 60% of Dvarakan population, TDC will come into action. Council members will be chosen by MADE from 1000 Dvarakans. The council will be the board of directors consisting of different departments' representatives as shown in Figure 18. Each representative will cover three departments, to maintain the discipline and check the functionality of the Martian settlement process. Labor and Commerce will be controlling mining and fuel management. Education and Agriculture representatives will look into research programs and food and oxygen management, while Colony Development will take care of water and electricity management and will improvise the infrastructure for future colonists. The entire mission will be monitored by the Defense and Health Department and will also be taking care of the smart card for the credit distribution within the colony. The External Affairs Department will look into tourism, broadcasting, and other administrative work. Every department's main objective will be to make a self-sustainable human settlement on Mars. TDC will also have an Earth representative who will check the functionality of the council but will not participate in Dvaraka's decision making process. The External Affairs Department will be communicating with Mission Control on Earth. When Dvaraka finally achieves self-sufficiency, the TDC will no longer be reliant on the financial system of Earth.

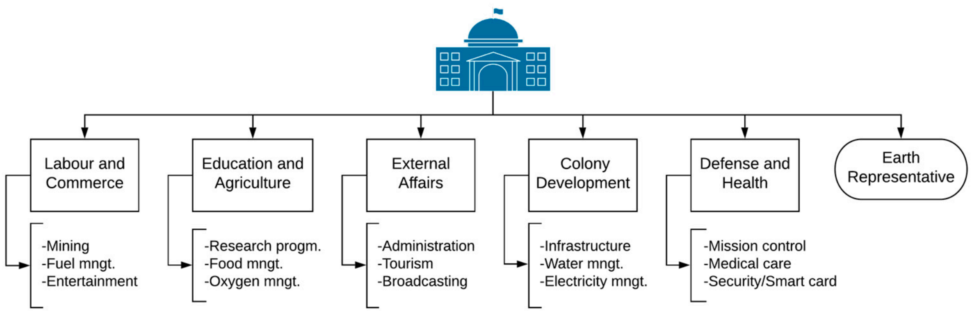


Figure 18. Departments of the Dvaraka Council.

5.2.2. Smart Card System

Credits will serve as the medium for the transfer of funds inside Dvaraka. This is because for a colony of 1000, which is the initial stage of full-scale colonization, the concept of inflation of money should be avoided. Hence, a credit card with a security hologram is introduced. Every Dvarakan will be given credit card with their biometric data on the chip. As far as the theft or misuse of the card is the hologram in the credit card could be verified using HSI [99–101]. Credit points will be added to this card depending on the number of hours that they have put in at work. During the training program on Earth, each candidate will be awarded with credits for their performance and progress. These credits will be loaded on the card and handed to them on their arrival to Mars so that they will have credit points to begin their new life. Every Dvarakan will be required to perform shifts that are eight hours long, and when those shifts are through, they will each be awarded 250 credit points. These credit points will be used for buying food, water, drinks and enjoy some entertainment. Each meal will cost them up to 20 credit points. Water and drinks will cost between 1–5 points, and entertainment will be costing 15 points per hour. A Dvarakan will need 126 points per day to maintain a quality of life that is considered typical. So, there will be a savings of around 124 points. The points that have been saved may be utilized on days that have been designated as "casualty" or "illness" days.

5.2.3. Worst Case Scenario

The 1000 people community is quite a big population to manage. If ever there is a commotion or a riot that needs to be controlled, the responsible person will be punished with a deduction of 100 credit points by defense representatives. If mass riots take place, in order to avoid a biased consequence, the cutting of resources will be divided. If an entire block starts turmoil then an Education Department Representative and a co-sign Earth Representative will deduct oxygen supply while the Colony Development person in co-sign with the Earth Representative will hold back water supply for the block. If any of the representatives go rogue, then Dvarakans can file a complaint on Human Resource Department on Earth Council and the Earth Representatives will be given instructions for actions. These precautions will help in smooth flow of Dvaraka.

6. Conclusions

In brief, considering all the factors and research, the Jezero crater is chosen as the most suitable site for the first settlement on Mars. The technical team has proposed a safe, sophisticated and eco-friendly infrastructural design for the first settlement. The materials used are environmentally friendly and can withstand the temperature variations on the Martian surface. The course has been planned for 26 years and includes 11 missions with 3 phases. The phases are described in detail with the economy layout and the budget comprising the money flow estimation. The economic flow between Earth and Mars has been discussed in detail in the respective section. The economic analysis has concluded that Dvaraka shall be debt free and independent of Earthly finances in the year 2060, thus rendering it a self-sustainable colony. In the social and aesthetic view of the colony, the team has pinned down the governance of the Martian society. The structure of MADE and The Dvaraka Council has also been sketched and its working procedure was discussed in detail. The currency used in Dvaraka has been replaced with smart card credits, the working of which was discussed. Additionally, the worst-case scenarios have been taken into consideration, which make this plan risk proof as well. Finally, the future of inhabiting a planet other than Earth, that seemed to be an illusion in the past, does not seem to be too estranged an idea anymore. With this idea, Earth will not be the only life supporting planet in the Solar System. With all the assumptions and estimations, our team has built a conceptual design for the first self-sustainable human settlement on mars—The Dvaraka Initiative.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/aerospace10030265/s1, Table S1. Contents and cost of the first five missions. Table S2. Contents and cost of the second five missions. Table S3. Colony Fuel Usage. Table S4. Fuel and payload calculations for Asteroid Mining. Table S5. Tourism Cost Scheme A. Table S6. Tourism Cost Scheme B. Table S7. Tourism Cost Scheme C. Table S8. Tourism Cost Scheme D. Table S9. Different Tourist Trip Trajectories in the year 2035. Table S10. A complete Cost Plan Analysis.

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Patel) and A.M.; project administration, A.M. and H.-C.W.; resources, A.M.; software, A.P. (Alice Phen), A.P. (Akash Patel) and A.M.; supervision, B.S., A.M. and H.-C.W.; validation, B.S., A.P. (Akash Patel) and A.M.; writing—original draft, A.M.; writing—review and editing, A.M. and H.-C.W. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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