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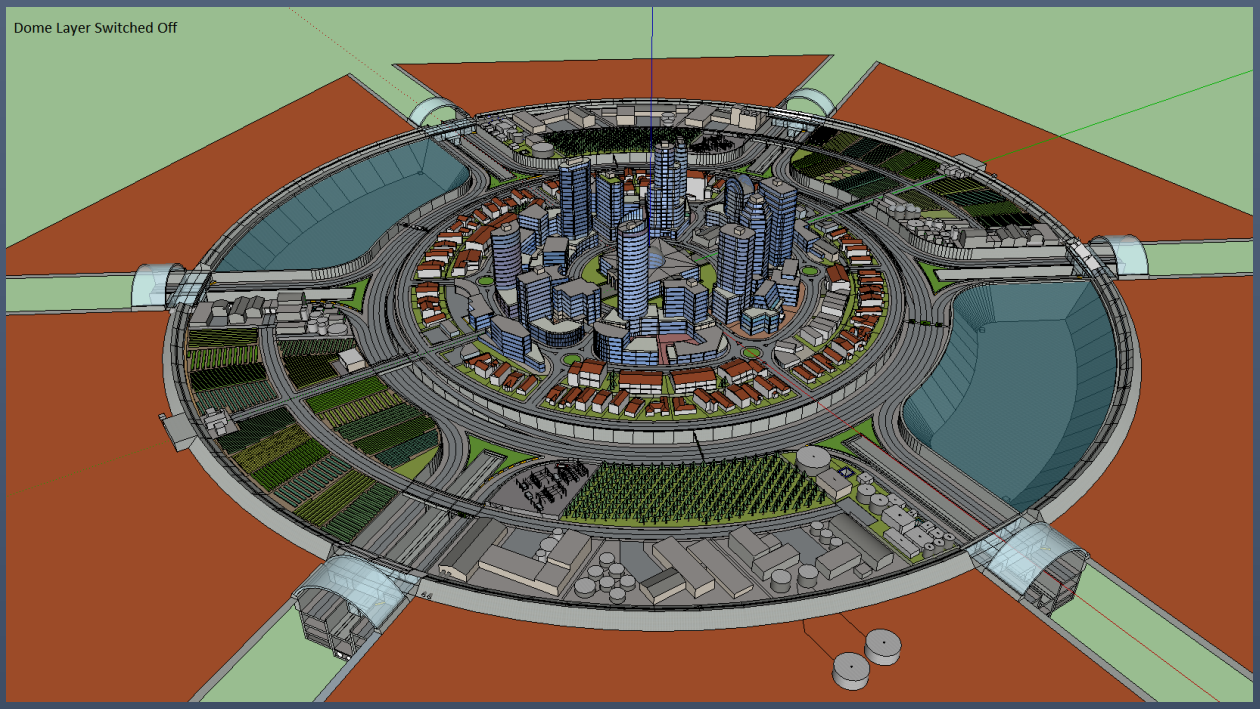

Revival of the Garden City for a New Purpose

THE MARS SOCIETY CITY STATE DESIGN CONTEST: DESIGN THE FIRST ONE MILLION PERSON CITY ON MARS SUBMITTAL

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Mars Society Design Contest: Design the First 1-Million Person City on Mars

Team: Planetary Development Systems

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Proposal Title: Revival of the Garden City for a New Purpose

Introduction

More than half a century of Mars exploration has shown us the red planet's potential to be the second home to humankind. Enriched with enough resources to support life, some see Mars as an opportunity to make humanity a multi-planetary species. Some take it as an inspiring challenge to push the boundaries of what humans can achieve. Envisioning a thriving colony on Mars seems plausible, but now the big question is, how should these cities be designed. Looking to history for inspiration, some of the lessons in the urban planning discipline can provide a lot of insight. The conglomeration of knowledge from urban planning, aerospace engineering, civil engineering, and various other sciences and engineering could help achieve a self-sustaining city on Mars and eventually beyond.

Background on the Garden City

Before we dive into the proposed city, we will be connecting the 19th century Garden City concept to 21st century Mars. In 1898, Ebenezer Howard wrote a book called *To-morrow: A Peaceful Path to Real Reform*. In this book, he discussed how the conditions of cities at the time were dismal and dirty, but a better future awaited. He created the idea of a city that would provide a higher quality of life (health-wise and environmental wise) and decent employment opportunities for its citizens. This ideal city included the best of both worlds: rural (Country) and urban (Town). These two make up part of 'the Three Magnets,' as seen in Figure 1 from his 1902 book. The Town magnet signified urban life with advantages such as social and economic opportunities, recreational facilities, high wages, better employment opportunities, and improved infrastructure. Meanwhile, the disadvantages were disconnection from nature, overcrowding, high cost of living, pollution, and unhealthy living conditions. The second magnet, Country, included the pros and cons of rural life. The Country offered natural beauty, healthy living conditions with clear air and abundant water, and affordable living. However, the Country also meant the absence of economic opportunities and social life, and the lack of proper infrastructure, which pushed people away, leaving deserted villages. The third magnet (Town-Country)

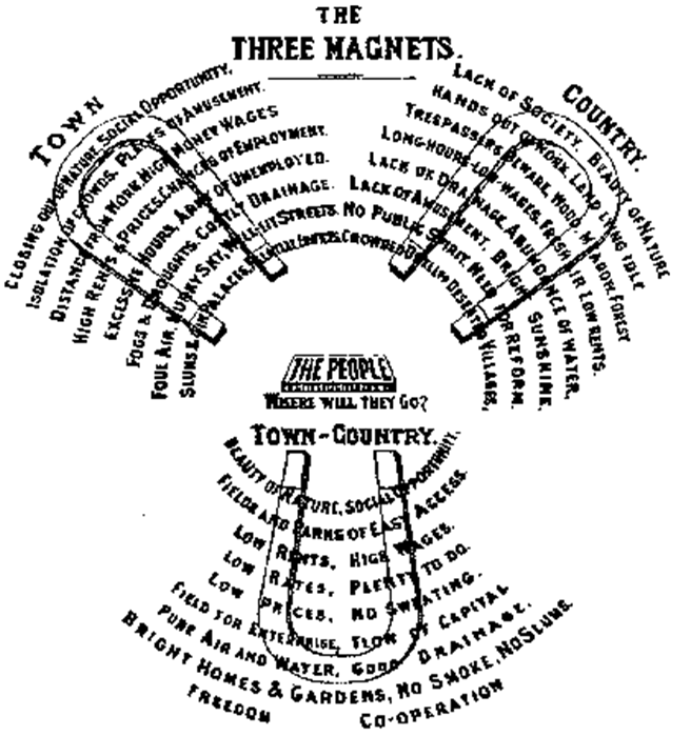


Figure 1: Howard's Three Magnets (1902)

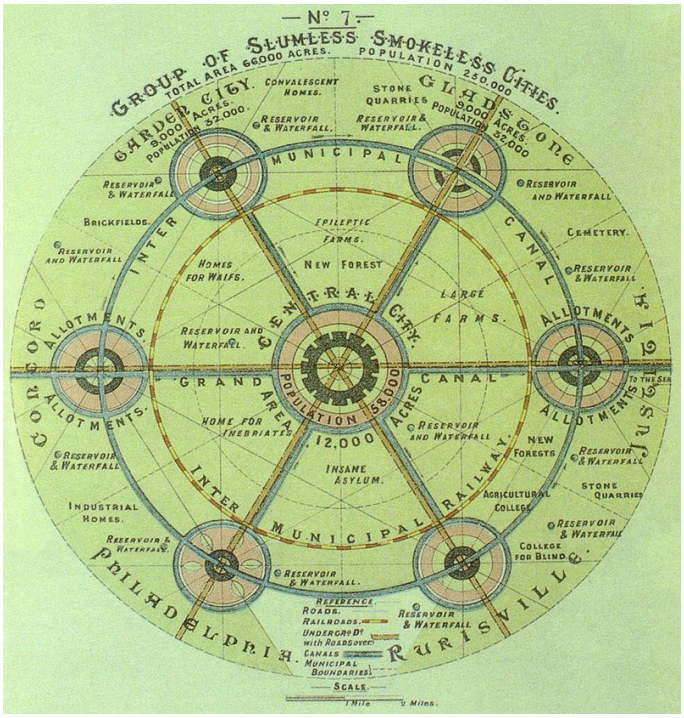


Figure 2: Ebenezer Howard's Garden City Diagram (1902)

represented Howard's utopia and was the combination of the best qualities of the first two magnets. It included the beauty of nature, social opportunity, access to recreational facilities and parks, affordable living with high wages, enterprise & opportunity, the flow of capital, healthy and aesthetically pleasing living environment, and vibrant public life with cooperation and freedom. The socio-economic concept from the three magnets formed the basis for the garden city.

Howard designed the garden city to be made up of six satellite towns that were to be 6,000 acres (2,400 ha) and house up to 32,000 people each with one 12,000-acre central city of 58,000 people grand totaling out to 250,000 people within a 66,000-acre area (shown in Figure 2). Each city was to be self-sufficient and when fully developed would expand to a new already planned garden city nearby. Howard went on to discuss people and markets within the garden city and how goods would move from point A to point B. Mainly, this focused on a local based economy with manufacturing, farming and buying locally. The majority if not all of the revenues generated would come from rents. Howard then went on to break revenue sources down into residential, agricultural, and industrial sectors. The revenues from the garden city would fund the operation and maintenance of the city, including capital expenditures for facilities such as the town hall or sewerage services. The book also elaborates on the water production system of the garden city relying on underground reservoirs for production and the storage facilities for the excess such as the canals between cities (light blue lines shown in Figure 2). Further, Howard discusses the separation of public and private work to avoid government or corporate monopolies. With the success of the first publication, Howard published the *Garden Cities of To*-Morrow in 1902, updating the previous version with visuals to envision the garden city from different viewpoints.

Howard's ideas were the realization of a utopian society that strived to grow smarter and create a better environment for its residents who were well acquainted with polluted industrial cities in England. His most famous diagram, as seen in Figure 2 (Howard, 1902)**,** is the main inspiration for the development on Mars. These self-contained garden cities provide a green environment with ample job opportunities while providing room for smart growth and private development. This design on Mars could be turned into self-sufficient zones that can strive to make the Martian city a closed-loop system.

Letchworth and Welwyn Health Case Study

Howard's garden city idea was so enchanting that he was able to convince investors to help him build one. His books not only started the Garden City movement, but also led to the creation of two garden cities named Letchworth, formed in 1903, and Welwyn in 1919; both are technically now suburbs of London, England, UK.

Table 1: 1933 England and Wales Vital Statistics

1933 England and Wales Vital Statistics	County Borough's	Urban Districts	Rural Districts
Death Rate	13.1	12.4	12.1
Infant Mortality	75	62	56
Scarlet Fever Attack Rate	3.4	2.98	1.93
Diphtheria Attack Rate	1.48	0.84	0.64
Puerperal Fever and Pyrexia Attack Rate per 1,000 births	15.5	10.9	9.0

Letchworth from the outset was not planned like other traditional cities at the turn of the 20th century. This city was about "creating a place that could support the physical, social, and psychological well-being of the people who were to live and work there" (Lewis, 2015).

After the *Sociology Effects of Garden Cities* study from Dugald Macfadyen in 1935 was published, it appears this quote was correct of Letchworth. The study measured key characteristics of a healthy community such as death rates, infant mortality, scarlet fever rates, diphtheria rates, puerperal fever and pyrexia attack rate per 1,000 births (Table 1). This data was compared to other nearby county boroughs, urban districts, and rural districts. Further, the study (Table 2) measured the death rate from pulmonary tuberculosis and infant mortality rate and compared it with the numbers from the county and England and Wales. The comparisons show that the design of the Letchworth Garden City provides a cleaner environment with healthier citizens. Similarly, another garden city, Welwyn had a higher quality of health than their surrounding cities (The British Medical Journal, 1930). The reason for this could be that the garden city redesigned the usual city's once narrow streets and relocated industries. Moving citizens away from pollution sources such as factories and putting them closer to agricultural belts seemed to have paid dividends. During Macfadyen's study, he noticed that most of the tuberculosis cases were imported from outside Letchworth. He noted that "there is evidence that in Garden Cities the spring of 'interest' (vital capacity or youth) remains active much longer than in large cities, that people who moved here to die twenty years ago have not succeeded in doing it yet" (Macfadyen, 1935). The levels of intellectuals in the city were also higher than average according to the city's librarians, to the point that "the young people, used all their time and mental energy to keep up with the increasing variety, individuality, and specialization of our older readers' interests" (Macfadyen, 1935). The study also points out the garden city's strong bias against alcohol. Macfadyen explains how many of the original "settlers" of the city were well aware of the havoc of drunkenness associated with most industrial cities at the time, thus they issued no license to sell alcohol within the city. The garden city focused on the feeling of cleanness and up-lift. This contributed to the city's natural vitality and generated expectations for its residents, which made for a self-respected, responsible, and healthy individual.

Year	Letchworth	County	England & Wales
General Death Rate			
1930	7.1	10.2	11.4
1931	7.2	10.3	12.3
1932	8.1	10.6	12.0
1933	9.9	10.8	12.3
1934	8.7	10.4	11.8
Infant Mortality			
1930	20	42	60
1931	41	46	66
1932	62	50	65
1933	30	42	64
1934	20	37	59
Death Rate from Pulmonary Tuberculosis			
1930	0.4	0.5	0.7
1931	0.3	0.4	0.7
1932	0.4	0.5	1.1
1933	0.4	0.5	0.6
1934	0.4	0.4	n/a

Table 2: Standard of Public Health (Macfadyen. P.253)

USS Theodore Roosevelt 2020 Coronavirus Outbreak

For a more recent example of impacts of living environment on health and well-being, we can consider the March 2020 coronavirus outbreak amongst the crew onboard the USS Theodore Roosevelt, with over a five-thousand "inhabitants" in an "isolated floating city." The virus spread among 900+ crew members like wildfire (Horton, 2020) to the point it put the aircraft carrier out of service for a few months, and much would be the same amongst crews on small Mars habitats. Match this scenario along with a weakened immune system from space travel to Mars, and it could become quite a deadly mix (Austin B. Bigley, 2018) and not to mention the possible negative psychological aspects of these close-quarter lifestyles.

The garden city case studies and recent USS Theodore Roosevelt example show that small prefabricated structures, underground empty lava tubes, or any plans (including SpaceX Heavy Starship) for that matter, where people live in such close quarters, should be considered as temporary housing. They would be better suited to provide shelter during the construction phase. Similarly, since the first habitats on Mars will most likely be small and dense, separating dirty land uses from living quarters will be essential. For long term development, the garden city design characteristics will be vital to having a self-sufficient and long-term sustaining city on Mars while also contributing to the health and well-being of the citizens living in it.

Proposed Regional Approach

Walter Christaller came up with a geographical theory known as Central Place Theory. In this theory, he explains the number, size, and location of human settlements in an urban hierarchy. This same principle of hierarchy is applied on the planning of Martian cities. For a better sense of the overall system, Unified Settlement Planning (USP) brings together Howard's Garden Cities, Christaller's Central Place Theory, and the work of economist August Lösch. This regional scale or in other words bulk planning is used to support development on a massive scale. This type of unified planning system was first thought up in the Soviet Union (Khodzhayev & Khorev, 1972) during the Khrushchev era and has recently started gaining traction in India. This approach will be used on Mars to expand the different Phases to different locations (as conceptualized in Figure 3), thus over time introducing resiliency to this urban pattern in case one of the Phases is damaged or

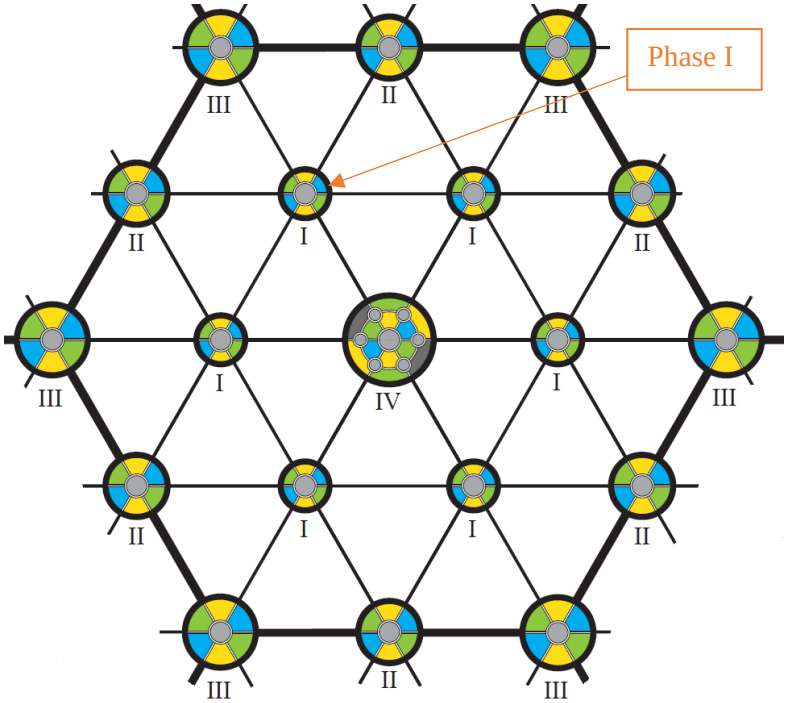


Figure 3: Conceptual - Explanatory Phases Map

compromised. Within each Phase, there are different land uses and sectors. Each Phase has a total set amount of internal square footage under the atmospheric and climate-controlled dome. This paper will only be focusing on the Phase I city structure out of the four total phase structures, which is the smallest and least complex of the four phases. Essentially, Phase I is scaled down to be compact, but more importantly, to be realistic.

Proposed City Design Specifics

The Mars City is envisioned as a redundant, resilient, efficient, and functional circular land use system under a dome. Figure 4 shows a surveyor style plat map of the proposed development. The overall design closely resembles the Garden City design, but with modifications to modernize and fit under a dome of realistic size as opposed to the 66,000-acre area of the 1902 garden city. For resiliency, civil infrastructures have been placed in multiple locations spaced far enough apart if one fails or an accident occurs near it, the other one would continue to function without being affected. Similarly, for efficiency, the design allows all the inhabitants to live within a small 538-foot radius, making everything in the city within walking or biking distance. The design also includes a below-

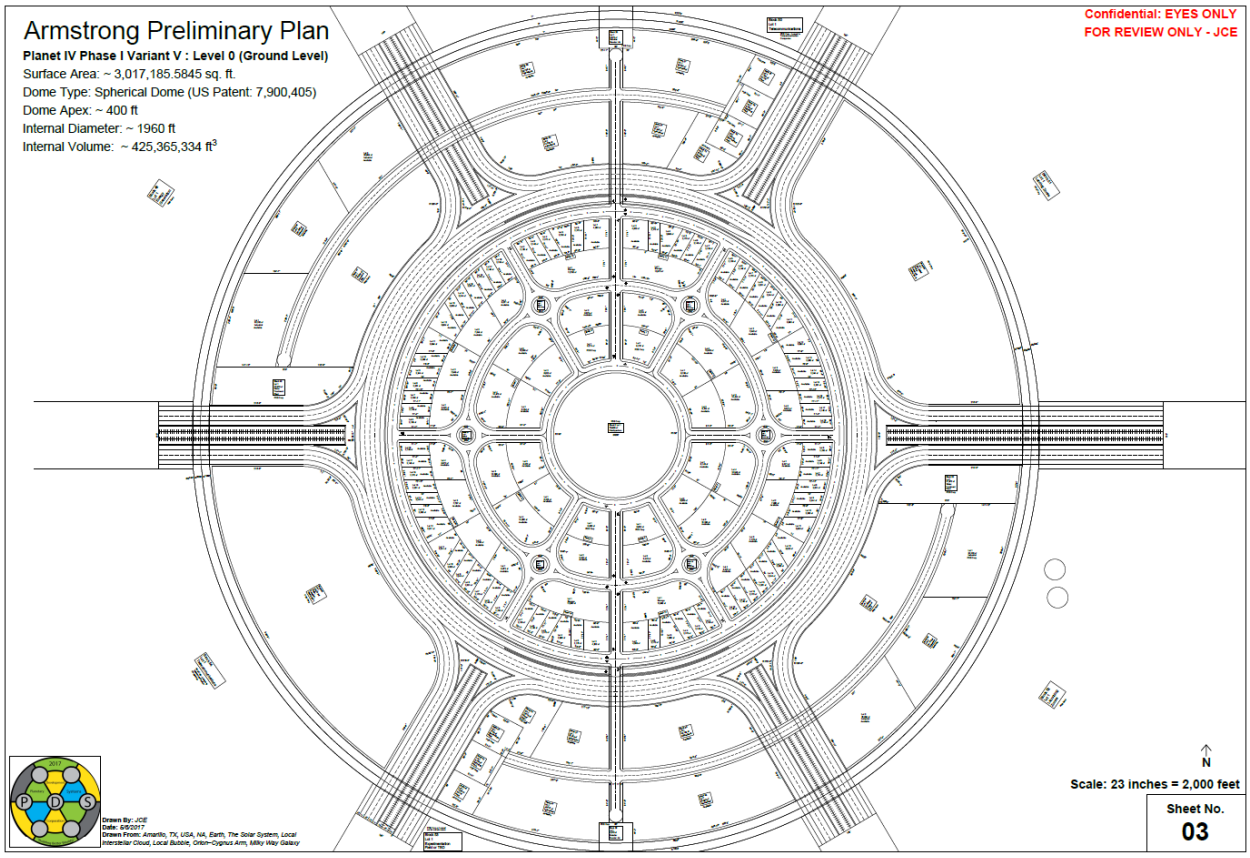


Figure 4: Phase I Variant V: Overall Design Schematic via satellite view (First city named Armstrong after Neil Armstrong)

grade central node transit hub (underground regional hyperloop), planned at the center of the city, which when developed, could help shape the city as a Transit Oriented Development and connect regionally to other phases. For a functional settlement in Mars, the design includes ample storage for water and enough room to produce food while producing oxygen to support the city

Centralization, another aspect for efficiency, will also be key to success, as opposed to more urban sprawl as seen on Earth or the city shown in SpaceX's first starship (BFR) unveiling slideshow from October 2017. Unlike Howard's cities having to compete with existing nearby cities and resources, this new proposal will be a stand-alone city with no nearby competitors. If anything, people will want to build or locate nearby this city, since this is where the resources will be. Utilities and transportation networks will be centralized and consolidated. This will lead to lower travel times for freight and commuters, thereby lowering costs and resource uses. One difference is that Howard wanted to use canals as a mode of transportation between cities, this simply will not be done because water will have a much more critical use for the city than a mode of transportation. Instead, it will be used for drinking, Sabatier reactor related processes, and reducing radiation exposure via the dome layer (Figure 8) by slowing down charged particles from space events such as cosmic rays or solar flares (NASA, 2002).

Dome Details/Structure Materials

The dome is one of the most critical aspect of the Mars city and the hardest structure to construct (Aniol, Dowd, & Platten, 2009). This type of structure was selected because it covers and protects from the hostile environment. The height of the dome creates opportunities for internal developments to expand upward. The dome will carry out many different jobs at once, such as radiation protection and keeping out super cold temperatures that come with deadly lower pressures from the outside as well as the occasional dust storm. Similarly, the structure will be aerodynamic enough to resist the possible impacts of high winds, while also preventing the buildup of sand from dust storms, which can usually lead to collapse of a structure from excessive weight.

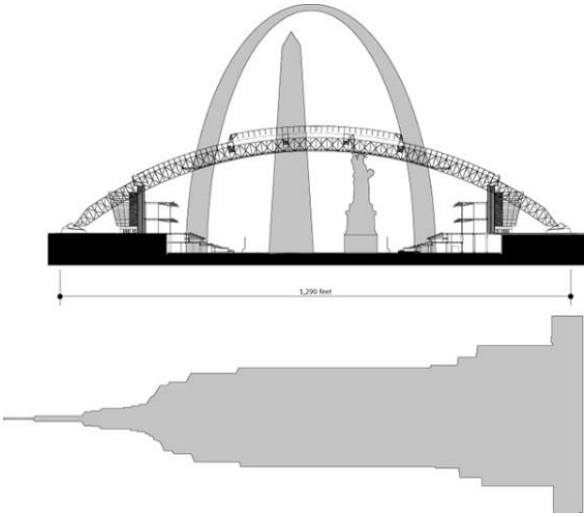


Figure 5: AT&T Stadium Dome Length Comparison (1,290 ft)
(ArchDaily. http://www.archdaily.com/37803/dallas-cowboys-stadium/)

The dome will have circular external foundation abutments similar to a tension ring, as seen in Figure 7 (# 24). The external abutment of 2,020 feet in diameter and the internal abutment diameter of 1,980 feet will provide adequate space to support the dome's concrete foundation, which has a wall of 10 feet above ground level. For comparison, this dome is about 710 feet longer than the dome stadium in Arlington, Texas (AT&T Stadium), as seen in Figure 5. The dome's radius is 980 feet in the interior and 1,020 feet on the exterior. The internal diameter is 1,960 feet with an interior space of around 70 acres (3,017,185.59 square feet to be exact). These figures along with the internal apex height of 400 feet were helpful in finding the interior volume of the dome using a spherical cap formula: $(\pi/3) * (Height)^2 * (3*(Radius) - (Height))$.

The total volume is 425,581,084.81 cubic feet using the spherical cap volume formula. This volume doesn't include the external transportation corridors that connect to the outlying cities in the six hexagonal spots – the spokes outside of the wheel. The volume will eventually determine the amount of energy required to keep the Heating Ventilation Air Conditioning (HVAC) system running.

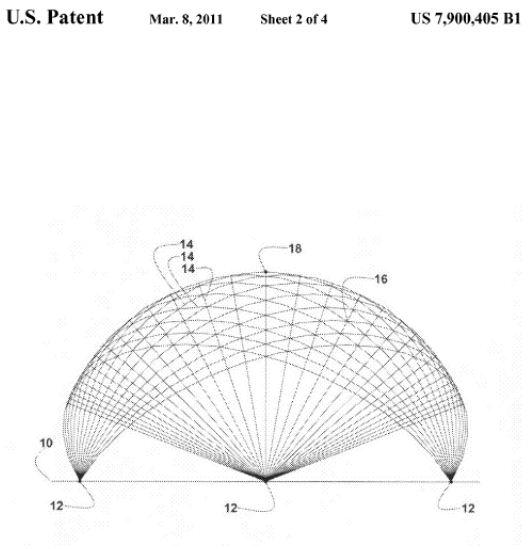


Figure 6: Front Elevation View of a Three-Way Spherical Grid Pattern

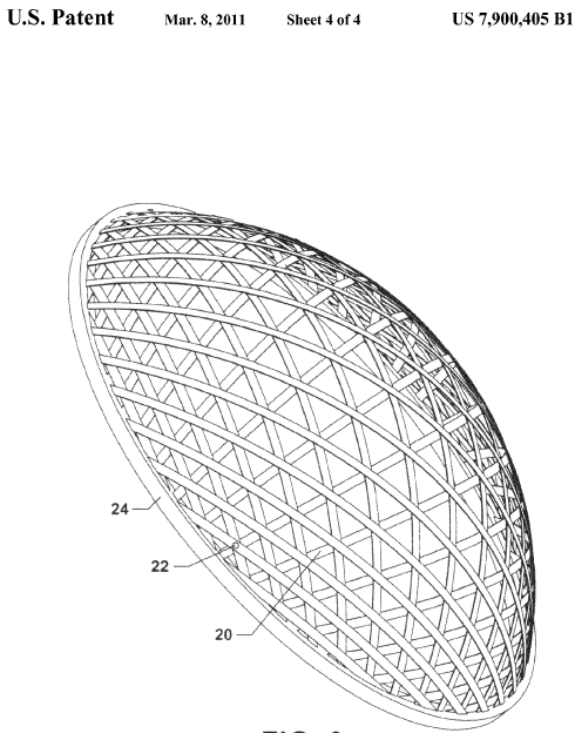


Figure 7: Perspective View of a Spherical Dome

The dome pattern chosen for this city is called a Spherical Dome based on US Patent 7,900,405 B1 (see Figure 6 and 7) by John Donald Jacoby approved in March 2011 (Author has permission to use in this paper). The hexagonal pattern matches over the city perfectly with regards to life support systems and the 6 external transportation corridors.

The transparent dome portion will be made out of a material called Ethylene tetrafluoroethylene (ETFE), manufactured and assembled by *Vector Foiltec*. This light weight, plastic-like material is made up of Hydrogen, Carbon, and Fluorine that will provide a multitude of benefits including a wide operability temperature range of -300F to 300F degrees and resistance against Ultraviolet (UV) Light, similar to ETFE resins used in the nuclear industry. The panels have the potential of being durable in dusty Mars as they have non-stick surface. An accelerated weathering test showed almost no deterioration on ETFE, in fact the first ETFE panels installed in 1982 at the Burgers Zoo in the Netherlands are still in use today showing very little signs of deterioration despite being out in the elements for nearly 40 years. More recent examples are the largest ETFE panels ever installed (300 feet in length) on the U.S. Bank Stadium in Minneapolis, MN in 2015 and the Allegiant Stadium in Las Vegas, NV in 2020.

The dome, to carry out the purpose of protection, will be layered, as shown in Figure 8. Starting with the exterior layer of 2 inches of ETFE, this layer will insulate or keep the cold air away from the next layer that contains warm air. Separated by another ETFE layer, the warm air layer will keep the purified water layer at a liquid state rather than frozen chunks of ice. Purified water is the better option than ice to acquire adequate sunlight for agricultural and other functions. This water layer should be more than one foot thick (Guetersloh, et al., 2006) to combat radiation events and to reduce or negate harmful radiation from reaching inhabitants. The last layer of ETFE, which will be facing the interior, will hold water and add additional protection to reduce radiation. One or more of the layers of ETFE will need to be tinted to reduce ultraviolet light from going through, while still allowing passage of sunlight for the agricultural sector. ETFE is self-cleaning with its non-stick surface, but a maintenance program and cleansing process to reduce the build-up on the dome frame is needed. Transparent aluminum (Aluminum Oxynitride, AlON) could also be used in one of the dome layers to support the structure. However, it is more expensive, does not reduce radiation levels as much, and requires a license from the U.S. government to access the material. Another material that could be used on the dome by using local resources, such as carbon and hydrogen, is Polyethylene plastic. However, Polyethylene plastic does not have the best radiation shielding properties.

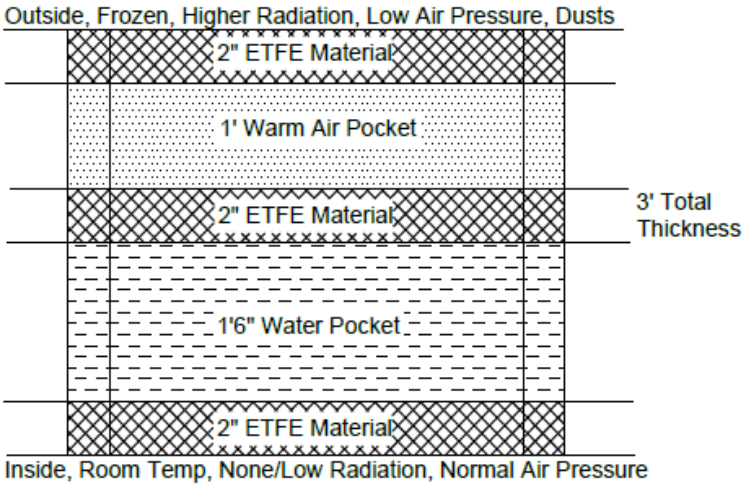


Figure 8: Typical Section Dome Layers Diagram (Not to scale)

At one time during the theoretical design process, we considered the dome to provide artificial rain to the whole city to clean surfaces and air. This idea was scrapped because the water could become contaminated from outside radiation. This could create free radicals within the water, which would be harmful to humans or any biological entity causing cancer (U.S. Department of Energy, 1993). Other impacts noted during the process include the interior noise levels, and research recommends sound to be kept down around 45 decibels (Connors, Harrison, & Akins, 1985). Similarly, with sewer and bio-fertilizer plants enclosed inside the dome, the odor can be an issue. Batch venting gaseous odors out to the exterior through tubular airlocks in the dome abutments, similar to horizontal smokestacks, might help minimize this problem or the gases could be burned off through the incinerators.

The foundation abutment of the dome (see Figure 9) will most likely be made of reinforced concrete comprising steel rebar and Portland cement. The constituents of Portland cement, CaO, SiO_2, Al_2O_3, Fe_2O_3, and Gypsum, are in the soil on Mars, as confirmed by the rover missions (see Figure 15). Another significant part about Portland cement is that it not only turns into limestone ($CaCO_3$) over time (Dempster, 1999), but when exposed to a carbon dioxide rich atmosphere, it will reduce interior oxygen loss over time. Oxygen and carbon dioxide

absorption from the concrete caused issues for Biosphere 2 in the early 1990s, but since this city will be located on Mars with a majority carbon dioxide atmosphere, this should not be a problem. The abutment walls and the dome will have to be layered to reduce oxygen losses and sustain proper air pressure and temperature.

Construction/Assembly

One of the first structures that will need to be assembled for the city will be the Sabatier reactor to create fuel for the SpaceX Starship's return trip, which will make the Mars to Earth journey cheaper than Earth to Mars. In the proposed design, this structure is termed as Sabatier Refinery because of the scale of fuel production. However, there is an issue with the toxic level of perchlorates in the Martian soil. Perchlorates, particularly the ones on Mars, are compounds containing chlorine existing in a mixture of calcium and magnesium. All rover and some lander missions on Mars have confirmed the presence of perchlorates at every landing site around the planet (M. H. Hecht, 2009), and each one of them showed around 0.5% levels in the soil which is a toxic level for humans (David, 2013). Side effects to humans include but not limited to thyroid inhibition, developmental issues in children, and higher systolic blood pressure. Perchlorates also impact vegetation/plants (He, 2013). Thus, the construction phase will not be as easy as heating Martian soil and 3D printing the structures. The soil will need to be processed and cleaned up first. Therefore, the second structure, if not the first, to be built, will need to be a soil processing facility to clean up the area. Ex Situ and in situ treatment options do exist but are expensive, difficult to operate, and time-consuming. Once the soil is cleaned up below toxic levels, the city construction can begin. Without the soil processing, the operation would be spreading around perchlorates and increasing the toxicity risk to inhabitants.

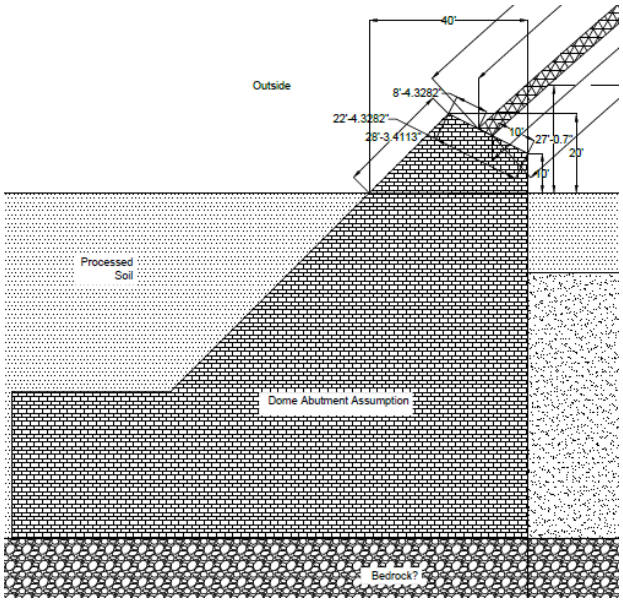


Figure 9: Dome Abutment assumption (Not to scale)

For the proposed development, the construction process could be 3D printing the dome abutment or tension ring (as seen in Figure 7 - #24 or 9), and related foundation structures. The dome's three-way grid frame (aluminum) and the ETFE panels placement might have to be done manually unless there is some kind of partnership between Caterpillar and Tesla on manufacturing automated large-scale electric powered construction equipment that can drop the panels into place while fitting in a little more than 26 feet diameter SpaceX Starship. After the dome, the delicate life support systems will need to be constructed to create a workable environment inside.

The Life Support Systems

The central system that will maintain and support this whole operation is similar to an HVAC system, as theoretically seen in Figure 10. Without this scaled-up system, carbon dioxide (CO_2) or oxygen (O_2) would most likely build up in parts of the city, creating either a poisonous or a flammable situation. Keeping the air clean and circulating creates a healthy environment, just like a typical HVAC system in a house does. Along with that same thought, there will be many intake and outtake vents around the city to facilitate this. The only difference between a house system and this one is that it will be connected to Sabatier reactors (Zubrin, Muscatello, & Berggren, 2013) to pump fresh air in (cyan) and soak up the used air (CO_2) (peach colored). The Methane (CH_4) gas byproduct from that reactor will be sent out to a storage tank farm and refrigerated for SpaceX Starship rocket propellant. The methane could also be sent to a Bosch Reactor for a closed-loop system, but carbon graphite build-up on the catalyst could be a long-term viability issue. The water from the Sabatier reactor will be sent to a water treatment plant via sewer line and forwarded into an electrolysis module that will split the hydrogen (H) gas and oxygen (O_2) up. Hydrogen will be recycled into the Sabatier Reactor process and the oxygen pumped into the HVAC system and out to the end-users for consumption. This new oxygen being shipped out to the end-user via sidewalk vents (as seen in Figure 11), will also need to be cooled to maintain the internal climate, this is where the heat sink operation steps in. Similar to a spacesuit, the city needs to maintain temperature too. Surprisingly enough, spacesuits needs more air conditioning for cooling air than for heating air in part to the human body generating heat. This same principle will be applied to the city. The heat sink system will be a closed-loop system that will exchange heat by storing the heat in water which has a higher thermal capacity compared to air or soil. As seen in Figure 10, amongst the many options for heat storage, the best location will be stored under the two reservoirs and possibly stored under the agricultural areas within the soil's moisture and not in the soil itself. Another location for the heat exchange could be the water layer in the dome structure as shown in Figure 8, but given the possible radiation impacts, the water could transform into a corrosive liquid that could damage the heat exchange loops. A better location could be the warm air pocket layer in the dome, but air is not as efficient as water when it comes to heat storage. At the apex of the interior dome, there will be a vent to recirculate the dry heat that rises. Furthermore, as a residential system requires an air filter, this system will require multiple filters that can be washed/dried and reused. This same system

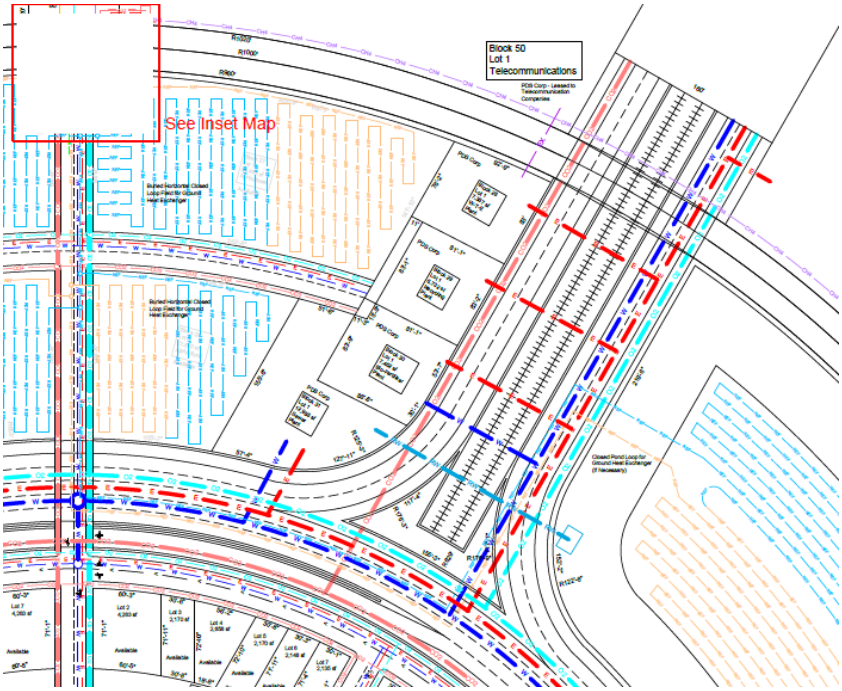


Figure 10: Theoretical Life Support & Heat Sink System (Image unreadable for security reasons)

that controls the interior temperature will also create a normalized pressure, such as in an air supported structure, while also delivering adequate oxygen and carbon dioxide removal services. As for maintenance, the ducts can easily be monitored and cleaned by automated machines on small rails. An important system like this will certainly need battery backup power from a Tesla PowerPack or something similar in scale attached to solar panels. To service external users outside of the city, such as larger factories and mines, or to connect life support to outlying cities, a transmission corridor is proposed, as seen in Figure 12.

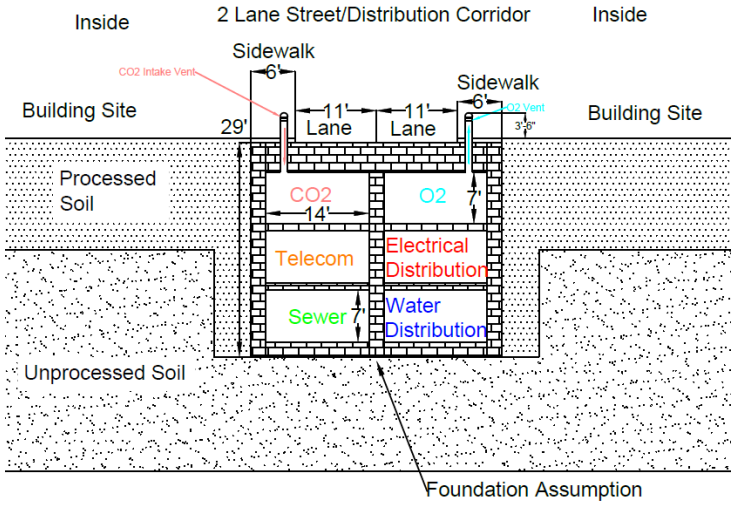


Figure 11: Proposed Internal Distribution Corridor schematic (Not to Scale)

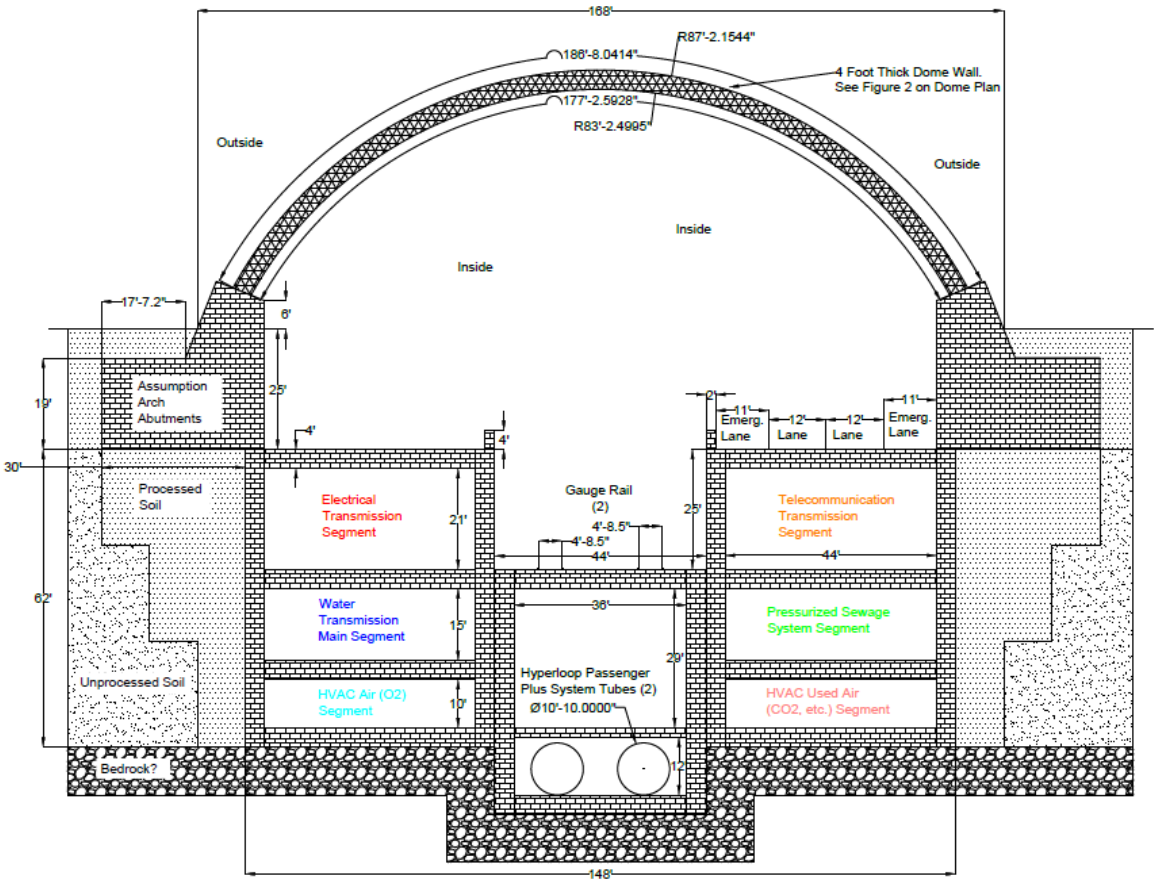


Figure 12: Proposed External Transmission Corridors schematic (Not to Scale) – At-grade variant, other variant includes sunken or underground tunnels. These are the lines seen on Figure 3 that connect the other outlying cities.

The overall operational schematic (as seen in Figure 13) is still a work in progress as more ideas and knowledge are applied to the city. This chart is a combination of life support systems and economic inputs/outputs of a city while showing resource flows. The chart also shows a few example industries and the possible imports and exports for the industrial processes related to nearby Martian geological minerals.

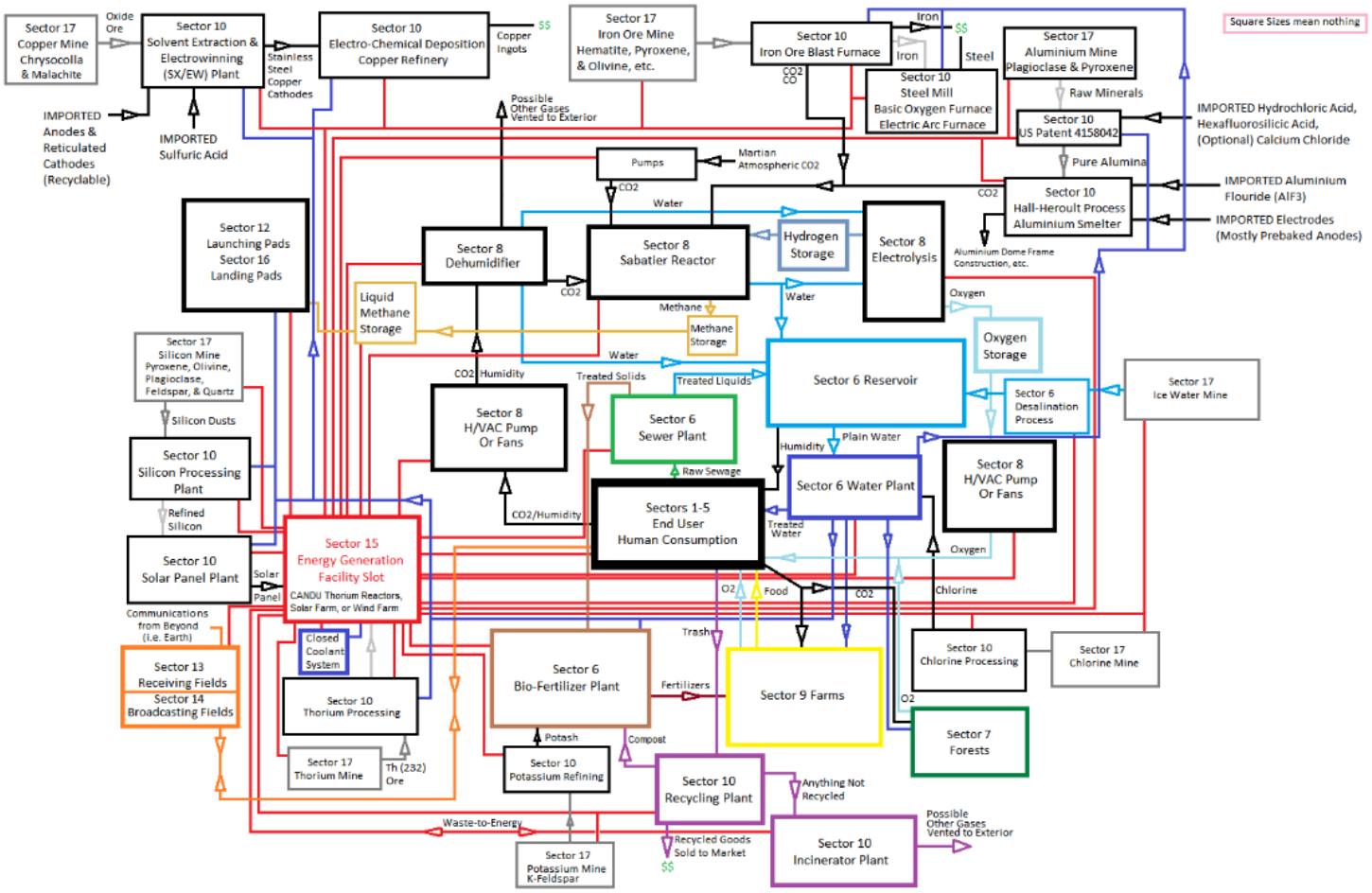
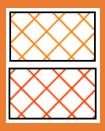
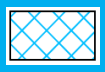
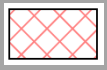


Figure 13: Overall Operational Schematic (Some Inputs & Outputs)

Land Use Sectors Breakdown

Once the dome and life support system, including utilities, are completed and operational, the city can begin focusing on land development and land uses. Inside this city, there will be 11 internal land use sectors, and outside there will be 6 external land use sectors. The difference between internal and external land uses is exactly what it seems, the internal land uses are inside the climate-controlled dome and the external land uses are outside the dome in the natural environment. The internal land uses are explained in Table 3 and seen on the map in Figure 14. The external land uses are more loosely defined (external developments will still be subject to review, such as a specific use permit for mining operations). They have no drawn boundaries and will certainly require a surveyor to create legal boundaries. These external uses can be seen below in Table 4 with examples.

Table 3: Phase I Variant V Land Use Breakdown (See Detail Sectors Guide [DSG] for full detail on each sector)				
Internal Land Use Categories	**Figure 14 Map Legend Color**	**Sector Details and Descriptions**	**Surface Square Footage**	**Surface %**
Sector 1 High Mixed Use		• Office, Labs, Hotels, and/or Retail • Between 20 and 25 floors • Basements Required	64,895.61	2.15%
Sector 2 Med Mixed Use		• Office, Labs, Retail, and/or Residential • Between 10 and 20 floors • Basements Required	119,364.80	3.96%
Sector 3 Med Residential		• Light Retail and Medium Residential (Apartments/Condos/townhomes) • Between 3 and 10 floors • Basements Required	128,519.21	4.26%
Sector 4 Low Residential		• Single Family Homes Only • Between 1 and 2 floors • Basements Optional	180,135.76	5.97%
Sector 5 Public Services		• Center Node Above Ground: Command Center/City Hall • Center Node Below Ground: Transit Center (Regional Hyperloop) • Fire, Security, Health Services • Educational/Meeting Hall uses • Permitting/Licensing Offices • Storage/Warehousing (Refrigeration possibly) Maintenance Buildings • Properties under PDS Corp ownership	149,340.75	4.95%
Sector 6 Water/Sewer		• Two Water Reservoirs • Two Water Production Plants • Two Wastewater Treatment Plants • Two Small Bio-fertilizer Plants • Properties under PDS Corp ownership	536,812.25	17.79%
Sector 7 Forest/Ag		• Oxygen Production/CO2 Reduction • Multi-purpose Area: Agricultural Trees • Meadow Green spaces • Properties under PDS Corp ownership	150,754.37	5.00%
Sector 8 Utility (Pink) & Transit Corridors (No Color)		• Electricity, Water, Pressurized Sewer, and Telecommunication corridors • License to operate private utilities through PDS Corp. (AT&T Fiber, etc.) • Two Life Support System Slots • HVAC System Intake/Outtake Lines • Heat Sink Tubes • Transmission and Distribution Corridors • 4 Lane Bikelanes will transition to 2 lane road	1,113,738.12	36.91%

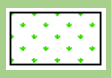
		• Road, Freight Rail, and Hyperloop • "Right-Of-Way" & Properties under PDS Corp ownership		
Sector 9 Agriculture		• Food Production • Cotton Production (Clothing Eventually) • Oxygen Production/CO2 Reduction • Properties can be subdivided and leased out	314,123.53	10.41%
Sector 10 Industry & Solid Waste		• Manufacturing, Processing, and Refining Facility slots • 5 Properties Leased Out or 1 Owned by PDS Corp (Sabatier Refinery Slot) • Two Small Solid Waste Incincerator facilities • Two Small Recycling Plants	225,579.37	7.48%
Sector 11 Parks & Rec		• Phase I: Parks and Landscaped Garden areas • Future Phases: Event Centers, Large Parks, Cemeteries • Open Green Space/Exercise Space • Oxygen Production/CO2 Reduction • Properties under PDS Corp ownership	33,921.79	1.12%
Total Phase I Land			**3,017,185.59**	**100.00%**

Table 4: External Land Uses (See Detail Sectors Guide [DSG] for full detail on each sector)	
External Sector Types:	**Sector Type Examples:**
Sector 12: Launching Pads	Pad 39-A for example, closer to the Sabatier Refinery internal slot
Sector 13: Antenna Relay Fields (Receiving)	Satellite Dishes/Large Relays (Example: SpaceX Tracking Station near Boca Chica, Texas)
Sector 14: Transmission Fields (Sending)	Transmitter Towers/Local Radio
Sector 15: Power Generation and Substations	Solar Fields at first, eventually Thorium based Nuclear Power Stations.
Sector 16: Landing Zones (Freight and/or Passenger)	Such as SpaceX Landing Zone 1 or 2 in Florida
Sector 17: Underdeveloped Land	17A: Olympus Mons National Park (Natural Uses) 17B: Surface Mining: Hematite - Iron Ore (Mining uses)

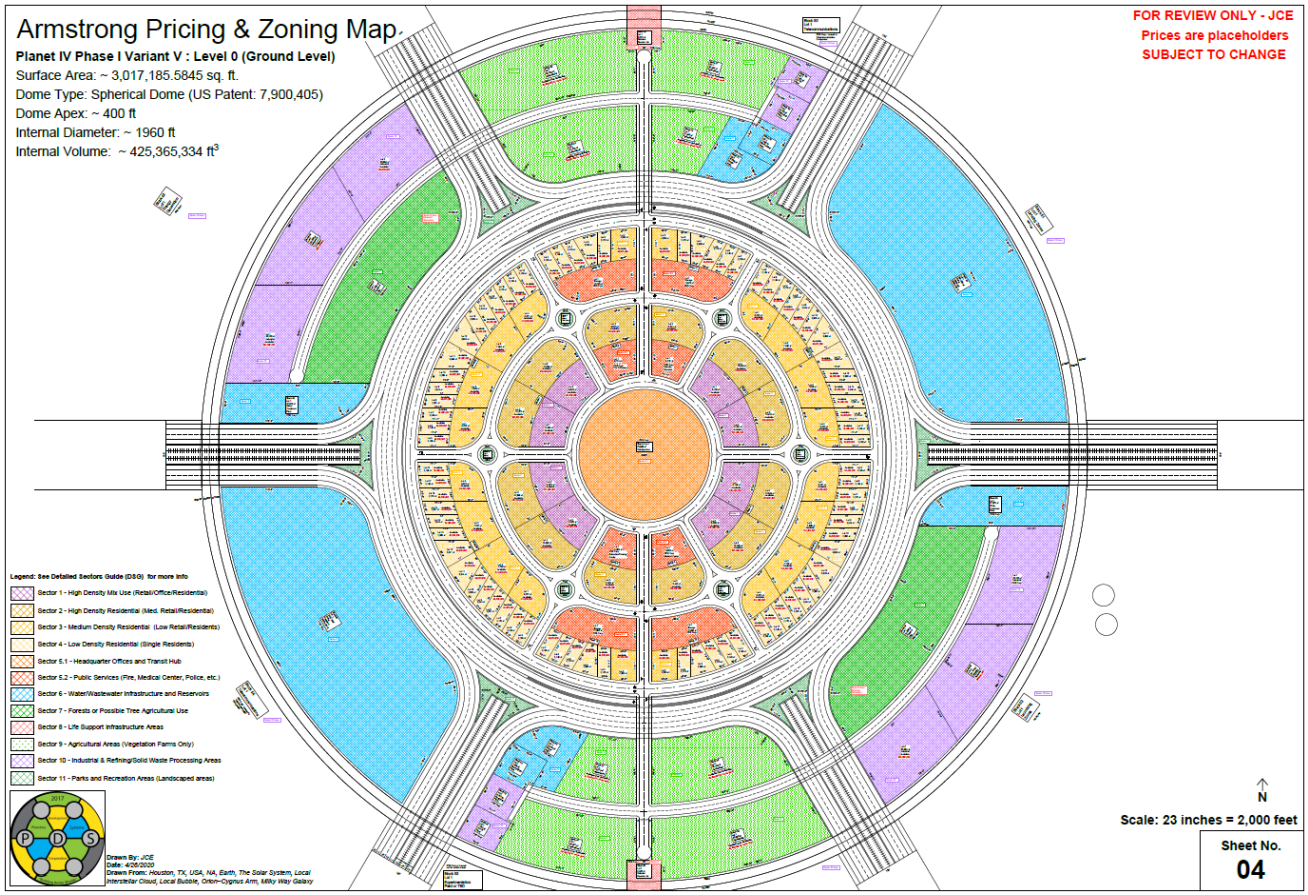


Figure 14: Zoning Map (Another PDF version can be seen on www.pdscorp.xyz on the portfolio page)

Aesthetics and Sense of Place

The land use plan is very closely associated with the aesthetics and livability of the city. Special attention has been given to separate incompatible uses and density, while providing visual buffer by using vegetation. As seen in the land use breakdown, Sector 11 is allocated for parks and open spaces. Green spaces are beneficial for physical and psychological health (Barton, 2017). They are a place of tranquility and relaxation and will create the feeling of being closer to nature. While the water reservoirs in Sector 6 will not be physically accessible for recreational use, the water bodies will also enhance the aesthetics of the space.

Additionally, the city will have inviting and functional public spaces throughout the built environment, whether in the form of plazas, pocket parks, or open spaces. The public spaces are a place for family, friends and social groups to gather. These are also areas for civic engagement. They include walkable streets, sidewalks, and any other pedestrian spaces, which also contribute to the sense of place. Elements of urban design, such as human-scale proportions, people-oriented design, walkability, and accessibility, will help create a foundation for a vibrant place. Further, the design of community appearances, social spaces, and the exteriors of private properties will also make the city visually pleasing and enjoyable to live, work, and play.

Economic System

Designing an economy from the ground up is not an easy task. There are no exact written instructions or financial formulas on how to do so, but to understand the economics of human civilization, Walt Whitman Rostow's 1960 book "*The Stages of Economic Growth" and* his 1971 book "*Politics and the Stages of Growth"* helps clarify the six stages of economic growth. In his writings, Rostow explains how society moves from an agricultural based economy to an industrialized one, then moving towards the search for quality. This principle can be used as a foundation to plan for the economic system in the Martian city.

Imports and exports create a basis for an economy, as shown in Rostow's books. While imports will be necessary for a city to maintain proper operations, increasing self-sufficiency and reducing overall imports remain the top priority. Imports can be broken down into categories based on the construction stages of the city. The amount and the schedule for imports are going to depend on the transportation options. If a fleet of SpaceX Starships is sent to Mars as proposed by Elon Musk, then imports could be broken down by ship to ship. As of now, we do not know how many Starships will be in this proposed fleet. Thus, imports will be broken down into city development stages. If each Starship can carry about 100 metric tons (100,000 kilograms) and the assumption is $500 per kilogram to get from Earth to Mars, then a fully loaded starship will cost $50,000,000 per launch. Now assuming there are already smaller habitats (possibly Starships), a few solar panel fields, some small *Square Roots* indoor farms, and a small crew on the planet, then the large-scale construction of the city can begin. In the first development stage, besides food and drinks rations for the crew, larger imports will include Sabatier reactor equipment for rocket fuel production, and life support uses, soil processing machinery for creating construction material for eventual concrete, and some construction machinery for dome frame/abutments depending on the space and weight of the Starship. The second stage will include additional construction equipment including, material refining machinery used to refine materials such as for steel rebar, and a small prototype aluminum smelter created by ELYSIS. This prototype small aluminum smelter produces a byproduct of only oxygen and is planned to be in production by 2024. The third stage will include stacks of ETFE panels for the dome, bags of different types of agricultural seeds for planting after the topsoil has been cleaned, and possibly frozen meats since this would be easier than importing live animals early on in the development process. Eventually, you could import frozen farm animal embryos once the necessary infrastructure is set up for receiving and raising them. The final stage of initial imports would be thorium processing machinery which would eventually refine minerals containing thorium and manufacture fuel rods for reactors to power the city and outlying cities. Estimated construction costs excluding transportation costs, could be between $2 to $5 billion (AT&T Stadium in Arlington cost around $1.5 billion in 2020 dollars and took four years to build while being 710 feet shorter), the construction timeline can vary from 6-7 years depending on the number of ships on the starship fleet. Since most construction materials are most likely in the soil on Mars (see Figure 15), the only real cost will be labor and transportation of the construction machinery, solar panels, and ETFE panels. The solar panels will be used early on to provide energy for the construction equipment batteries. Again, these are estimates, as there are too many variables to consider to give an exact figure. While the initial costs of construction will be high, the city from the outset of construction is designed to be self-sufficient in

the long run. The goal is to have a facility life span of 50 years or longer with proper routine maintenance. Maintenance will be vital to prolonging the infrastructure of the city. One major maintenance item with the highest cost and time consumption will be the joints in the dome between the ETFE panels and the frame. Given the possible warm and cold weather cycles with expansion and contraction, the city will need proper maintenance to sustain an air-tight and pressurized superstructure.

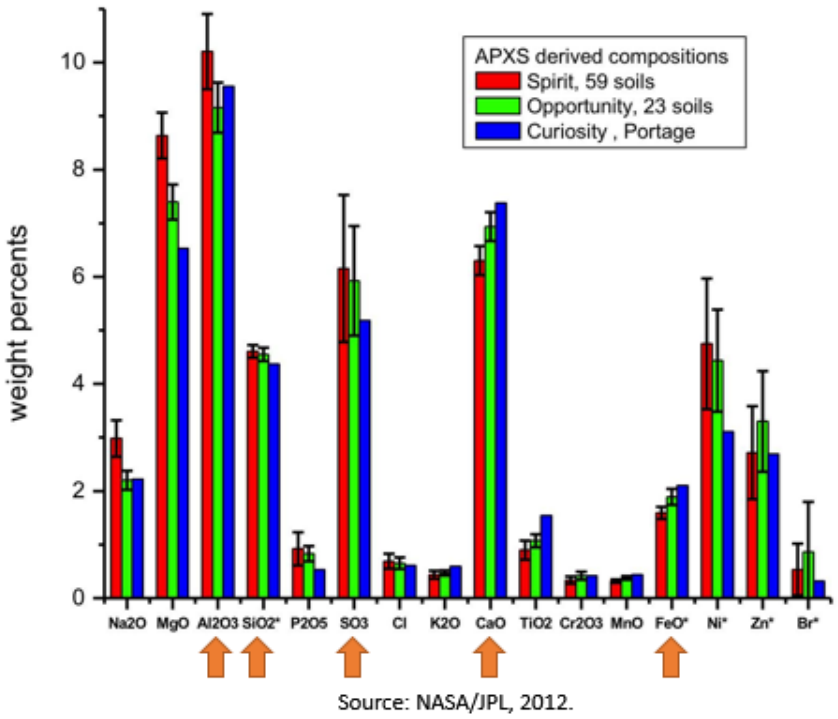


Figure 15: Portland cement ingredients (Orange arrows) at rover testing sites on Mars (NASA/JPL-Caltech/University of Guelph, 2012)

As of June 30, 2020, there are no commodities, agricultural or metallurgical, that are profitable exporting from Mars, given their current trading prices in the market. If $200 per kilogram is the transportation cost from Mars to Earth, and the maximum storage weight of a SpaceX Starship is around 100 metric tons (100,000 kilograms), then the transportation cost alone makes exporting prohibitive, as the material exported needs to be worth more than $20,000,000 in the marketplace just to recoup the transportation costs. Rare Earth minerals (e.g. Neodymium, Scandium) could one day be up there in price if demand keeps going up and supply continues to dwindle on Earth, but one would have to confirm that those minerals are on Mars in economical viable quantities first. That being said, physical materials might be out of the picture for now, but software and other digital intellectual property could be one means of economic income. There will be plenty of office and lab space offered in the city to innovate. The necessary telecommunications infrastructure, along with possibly Starlink, will be in place to transmit the work to Earth, with about a 20-minute delay of course. Along this same line, there could be software patents and licensing fees that could raise revenues for licensed businesses.

While imports and exports are important functions to be economically sustainable, maintenance of the city will also be essential for the long-term stability of the Mars economy. The proposed maintenance program will be funded by monthly user fees such as water and electrical fees to maintain their respective systems. Similarly, flat fees will be assessed monthly for sewer, fiber telecommunications/Starlink (if applicable), solid waste/recycling systems, and dome related life support systems. Property taxes or rental fees could be assessed if the city operator were contracted to develop a parcel of property for a separate entity, which could also open the door to mortgage

options. Industrial uses in Sector 10 could be assessed for additional fees for batch venting non-recyclable gaseous pollution to the exterior. Sales taxes could be assessed as a set rate on retail/industrial uses, however there should be no personal income taxes. Other sources of maintenance income would be the materials sold from recycling centers to Sector 10 factories, and bio-fertilizer sold to renters in Sector 7 and Sector 9. All of these incomes could not only provide needed maintenance funds, but also provide an opportunity to apply for loans or gain access to credit lines if necessary. This would be similar to how any city puts out bond proposals to voters for public works such as water/sewer system or roadway improvement projects. Further, if a corporation is to operate and maintain the cities while remaining on or under budget, it could create an opportunity to have surplus revenue that could be passed along to shareholders/employees/residents in the form of dividends like a publicly-traded Real Estate Investment Trust (REIT).

Once established, the city could consider creating local currency and possibly minting coins or printing cash with bar codes. Further, the city can explore innovative ways to connect the economy with social well-being and civic engagement. One example of innovative implementation of local currency is seen in Tel Aviv-Yafo, Israel and Liverpool, UK through an iPhone application called *Colu*. The app allows users to earn rewards (coins) by participating in civic activities around their city that the user can then spend in participating local shops, which in turn strengthens small businesses and the local economy.

Political System and Potential Culture

The political system would follow closely to a functional organization structure (as seen in Figure 16) such as a business would have along with geographical divisions. To be specific, as a private venture with possible government financial backing, there will be employees/contractors, board members, a chief executive/chairman, and shareholders, where employees will also be shareholders. The elected board shall govern as elected by the shareholders over the entire geographical control area, but each colony/city will have their own local board with local controls. The closest example of this could be the Dutch East India Company (VOC) of the 17th and 18th centuries possessing quasi-governmental powers by having its own regulations, fleet of ships, standing army, coinage, factories/colonies around the Indian/Pacific Oceans, and the ability to execute convicts if necessary. If the majority shareholder keeps the majority of the company in their family over time, it could eventually morph into a proto-constitutional monarchy, much like the Ford Motor Company is today in regards to voting control (Muller, 2010). However, Ford does not have a geographical control component much like the VOC during their tenure. An example we can consider would be the United Kingdom as a company, the Queen would be CEO/Majority Shareholder, Prime Minister would be Chief Operations Officer (COO), Chancellor of the Exchequer would be Chief Financial Officer (CFO), Home Secretary could fall under Chief Information Officer (CIO), and the upper legislative house (House of Lords) would be elected by shareholders to the Appointed Board of Directors while the lower house (House of Commons) would elected by citizens in Geographical areas. The judiciary will uphold and enforce the regulations approved by the organization.

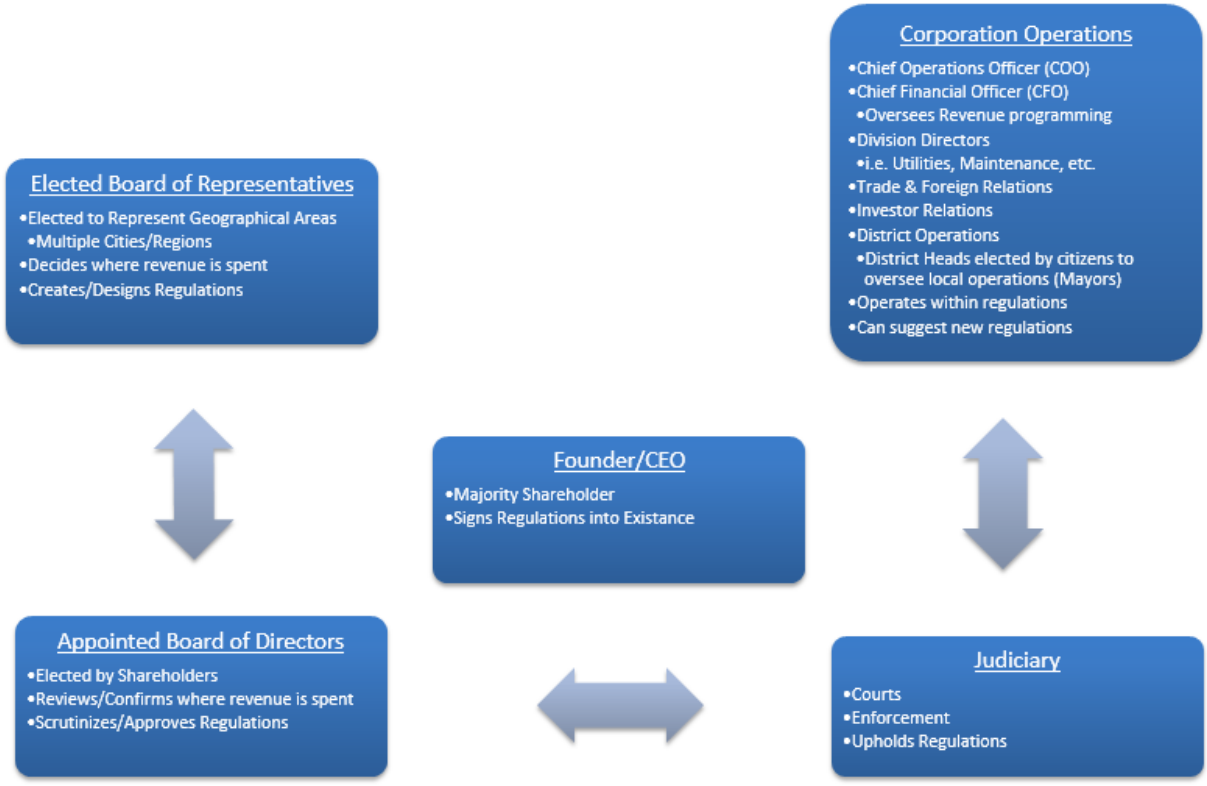


Figure 16: Hypothetical organization structure (Similar to Parliamentarian) and some example functions

Some of the facets of culture in these cities will take care of themselves much as the culture did in the colonies of the New World in North and South America, once European based now have their own foods/recipes, slang words, and language accents to name a few. A way of life will not be formed or forced by the governing body. However, the governing body will oversee design of these cities that will support personal and social wellbeing. The community spaces (Sector 11 and Sector 17 parks) will provide opportunities for social interaction and civic engagement which in turn encourages people to form a stronger sense of community. Similarly, another aspect of culture and upholding society over time is the educational system. All children will be taught foundational education and survival skills to create a solid base. Youths will have the options to get some essential skills training to join the workforce or pursue additional higher education. Meanwhile, the education will prioritize creativity, STEM, interdisciplinary thinking, and knowledge sharing to foster a culture of innovation and collaboration, allowing these cities to develop new knowledge and discoveries. For a high quality of life, music, art and other creative outlets will be encouraged. Further, the city design, with parks and trails, promote an active lifestyle with physical activities. In the opinion of the authors, sports like basketball may work on Mars with lesser gravity. While cycling may be one of the primary modes of transportation early on, it could also be a sport. However, since these cities will be a breeding grounds of innovation, there are vast possibilities of new sports, music or art forms that the new colonists and citizens will come up.

Conclusion

Building on past lessons, and newer technological advances, this modularized city on Mars is an effort to open a new door for humanity. The city aims to provide the necessities of life, while also protecting from the hostile conditions of Mars. The hope is to create an environment with a reminder of what home is like back on Earth, while also creating new social, economic, and scientific opportunities for anyone who chooses. As this society grows, the city will grow with them over time, and for that, this Phase I will provide the foundation for a much larger colony system.

Before selecting a final site, it will be crucial to complete a land suitability analysis, as the site selection and the development process will depend on material science and the geological minerals available on Mars. To move forward, we need better datasets and detailed studies. Most importantly, the design is a concept and needs to be further developed, studied, and tested by experts in civil engineering, structural engineering, construction science, and aerospace engineering, among many other fields. This city proposal is a work in progress and is continually improving as new knowledge is applied to the design. Further, the design process will be iterative. As humans navigate the challenges of developing a city on Mars, even the first couple of years on Mars, maybe decades, may not be enjoyable. There will be many challenges, and sand will get everywhere (hopefully not with perchlorates). The adversities and uncertainty of the new venture might push us to be more adaptive, innovative, and collaborative to create a sustainable habitat and a more resilient future for humans.

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