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Martian Modules: Design of a Programmable Martian Settlement

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Martian Modules: Design of a Programmable Martian Settlement

by

Craig A. Trover

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Architecture
School of Architecture and Community Design
College of The Arts
University of South Florida

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Kenneth P. Kroger, M. Arch.
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Finally, I give a special thanks to NASA, for everything.

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ABSTRACT

The evolution of human beings is marked by adaptation. The ability to adapt to and manipulate our environment is one definer of intelligence, and ours is unique among life on Earth. Since moving off of the African Continent, humans have migrated to inhabit every part of the Earth. Human existence and perpetuity in the universe depends upon the success of this adaptation, and inevitably, migrating off of this planet. The technological advances being developed today will change our way of life, and enable people to travel to and live permanently on the Moon and Mars. This study involves the architectural design and construction of a completely programmable permanent Martian settlement in the year 2050.

Previous studies and proposals for Martian architecture rely mostly on existing technology. The first people are not expected to reach Mars until 2030, and new and emerging technologies will radically affect the designs being considered today. Technical challenges constrain designers of space architecture today, and scientific developments will solve many of these. This study seeks to explore how new technology can positively affect the architecture of the future, affording more comfortable and livable space on Mars.

With a construction date of 2050, this project differs from others by benefitting from the next four decades of profound technological advancement. Leading Futurist Raymond Kurzweil predicts that the technological singularity is within this time frame, and that the 21st Century will, “Witness on the order of 20,000 years of progress (at today’s rate of progress) (Kurzweil, Law of Accelerating Change).” This thesis theorizes that nanotechnology will enable the deployment of a completely self-constructing and programmable permanent Martian settlement designed from

a series of spatial modules. The anticipated results include a modular system of architectural spaces, and an increased awareness of the architectural benefits of emerging technologies as they relate to future space architecture.

1. INTRODUCTION

"We are much closer today to being able to send humans to Mars than we were to being able to send men to the moon in 1961, and we were there eight years later. Given the will, we could have humans on Mars within a decade (Robert Zubrin)."

The nature of this project requires making broad assumptions and speculations about the development of space and technology in the future. Current plans are to complete the International Space Station in 2010, and NASA plans a return of humans to the moon by 2020, and the development of a semi-permanently occupied lunar base as a platform for future missions to Mars in 2030. The proposal for a permanent Martian settlement in 2050, based off of these benchmarks, is well within the possibly of technology at today's rate.

The ability of people to adapt to new environments is crucial to its own survival and ultimate perpetuity in the universe. Our species depends upon this ability to inhabit other worlds beyond our home planet, considering the inevitability and eventuality of a planetary-scale cataclysmic event. The purpose of this study is not to debate the morals and ethics of travelling to and settling on Mars, or even the possibility of doing so, but rather to explore and define the spatial needs and requirements of the first permanent human inhabitants on the surface of another planet, and explore the benefits, advantages and potential for new technology and materials. For those opposed to the development of Mars and other bodies, or "Red Martians," this author assumes that any life found on Mars will be primitive and that the impacts caused by a human presence will benefit that life as well as our own.

As opposed to the Moon, it is assumed that Mars will be the first permanently occupied body beyond Earth because of its diurnal cycle and material resources. Accepting that near-future reality as the imperative goal of current space exploration, the need for architectural dialog arises. Prior to this point in time, all structures designed in space have been temporary or semi-permanent habitats, constrained by current technologies and materials. As a result, architectural quality has been neglected or suffered primarily due to financial and engineering restraints. Engineers and project managers have been the primary decision makers in most projects, with architects playing a minor role, if any at all. Considering the rapid development of technology, materials, robotics and computers, coupled with a wealth of material resources on Mars, it is clear that the actual method of design and construction of this future settlement will be drastically more advanced than current proposals, theories, and imaginations suggest. Overpopulation, climate change and resource shortages here on Earth will provide sufficient motivation, desire, and incentives for humans to migrate permanently to Mars and other planetary bodies. A research project such as this, 40 years into the future, requires creating a theoretical framework making assumptions, projections, and speculations allowing the design process to begin.

1.1 Theoretical Framework

Planning space missions is, in many ways similar to urban design and large architectural commissions. The master plan or vision is often ten or more years away from realization, funding is not always secure, leadership and directives change over the course of time, and new technologies affect the processes, all of which combine to alter the end result. This "change" and revision is natural and inherent considering the scope and scale of the projects involved, and this amount of this change can only be predicted to accelerate as man's knowledge base and the size and budget of humanity's endeavors continues to increase exponentially.

This project proposes a permanently occupied programmable settlement on Mars, planned for occupation on the Martian surface in the year 2050. By this time, NASA, the European Space Agency, China, India and Japan will have met with varying levels of success with manned and unmanned missions to the Moon and Mars and have proven sufficient material resources to enable permanent occupation in self-sustaining settlements. By 2050, a mining/launching outpost has been continuously occupied on the Moon for more than twenty years and has proven the feasibility of in-situ resource utilization (ISRU), commercial mining potential, and has greatly reduced the cost of launching into space via the exploitation of a reduced gravitational field. NASA astronauts have made several exploratory expeditions to Mars, and the HABs and other similar habitats have proven to be a viable research facility and suitable semi-permanent habitat. The NASA Mars Design Reference Mission has been a success, and multinational efforts are underway to construct the first permanent human settlements. The fully-occupied settlement is designed to accommodate approximately 100 permanent settlers on the surface of Mars. The choice of 100 people is based on a historical reference to similar projects of this nature (Georgi Petrov, Kim Stanley Robinson), and presents a large enough number to warrant the study and investigation of social psychological considerations and sustainability in terms of food production and power generation into the architectural scheme.

The astronauts have spent considerable time determining the existence of resources such as water, oxygen, and fuel with techniques for extraction from the Martian regolith/atmosphere as well as choosing the site for the construction of the first permanent structures on the planet. Current proposals involve VTOLs (vertical take-off and landers) for the initial exploration trips to Mars. Most of the current theory for these expeditions are defined simplicity, affordability, and modularity. These models are constrained by the parameters set forth by the NASA Mars Design Reference Mission and limit the size and mass of anything leaving Earth to the rockets that are in existence today. These mass limits can be considerably increased in the reduced gravity of the Moon. Obviously, things forty years from now will be accomplished with drastically different methods and this project aims to take advantage of and explore the potential for these emerging technologies.

Understanding the differences between initial expeditions to Mars, all prior development on the Moon, and the first permanent settlements on Mars is paramount in understanding the nature of this project. Before humans travel to Mars, we will travel to the Moon again. The reasons for choosing Mars for this project are numerous, and outside the scope of this work. The Moon will serve more as an outpost or base as opposed to a permanent settlement for many reasons. In short, Mars is a better candidate for human settlement, and “All of the resources needed to support life support are available in some form on the surface of Mars and these resources can be used to extend human exploration of the Martian surface” (McKay 1994). An abundance of frozen water exists at the poles and perhaps just beneath the surface at mid latitudes, and Mars has diurnal cycle of 24 hours and 37 minutes- which is critical for plant growth and surface gravity of ~1/3e vs. the Moon’s ~1/6e. However, the Moon will serve an important role as a mining facility, research testing base and launch pad. Mars was chosen for its relative proximity in the solar system, temperate climate, and diurnal cycle. The Martian day being only 37 minutes longer than that of Earth is crucial for the growth and survival of plants as a producer of oxygen and food source, and anywhere humans settle, we will need plants to survive. However, the most important reason relates to distance. In terms of astronomical distance between objects in our solar system, Mars is really only a stone’s throw away, and currently the only planet that we are able to safely explore and inhabit. These factors, along with numerous other reasons, render Mars the initial candidate in our solar system to explore and settle. With the planet Mars chosen, and scope and context of the project defined, it is important to examine the underlying challenges that threaten the success of any mission of this nature.

1.2 Human Factors

The selection and use of the word permanent in the body of this thesis places deliberate emphasis on the difference between the initial trips to Mars and the first permanent settlements. It also presents a contrast between the majority of proposals for Martian designs and this thesis. It is of a personal view that the first permanent habitable structures on Mars are distinctly different from everything else ever built on Earth or launched, including every satellite, vehicles, or station NASA has designed, the ISS/MIR, and all future development on the Moon/Mars. Every other object either serves multiple roles as a vehicle/habitat, or begins its mission with a predetermined end. Needing permanence, the design and architecture of the habitat and living space module becomes a more critical factor and driving force in the design.

Humans are more able to cope with difficult conditions or circumstances when a short time frame of relief is known. This is not the case with Mars, as any hope for relief or rescue will be at least several months under ideal circumstances, with respect to each planet's orbit. Consequently, the effects of isolation, remoteness, and claustrophobia, coupled with the extremely hostile environment on Mars will prove to be perhaps the greatest challenge to humans on Mars. These human factors must be studied and completely understood before any serious design can be explored. As defined by www.about.com, human factors is, "A discipline of study that deals with human-machine interface. Human Factors deals with the psychological, social, physical, biological and safety characteristics of a user and the system the user is in." In an essence, the entire Martian settlement is a machine, and the spatial interface between the inhabitants and the structure will provide the greatest opportunity to mediate the negative effects of dwelling in such an extreme environment.

Previous studies and current trends suggest a modular approach to construction of a permanent Martian settlement. This study will take aim at the idea of the human module, and establishing the needs for the first permanent living spaces on the surface of another planet. With the issues and challenges surrounding the human individual on Mars addressed and met, similar design solutions can be applied to the larger scale and planning of the full settlement. Providing spaces that serve basic human needs under extreme conditions will be a minimum necesity for successful occupation of the permanent settlement. With carefully implemented architectural design and efficient space planning techniques, the spaces themselves can become more hospitable and comfortable, producing a greater perceived sense of volume. Views outward will be critical to providing a sense of place and relief from the claustrophobic conditions within the sealed pressurized environment of the settlement. Studies suggest that extended missions with limited ranges of sight adversely affect the ability to focus the eye on objects at a distance. Case studies examining the social structure and challenges involving dwelling in extreme environments include arctic/Antarctic research facilities. Results demonstrate a clear need for a definite division of space, and a certain balance between private and public space. The proportion and amount of personal, public, an social space will be critical to designing a settlement that is both livable and efficient.

The relationship and placement of these living space modules, combined with the distribution of shared spaces, circulation, and other functional components of the settlement will play a large role in the success of the settlement. The social structure, crew selection and overall organization will be defined early, to allow each component to be incorporated and integrated into the design scheme. At the organizational level, private and shared spaces on Mars will also prove to be an issue, and psychology will serve more pronounced role than design projects here on Earth.

Ryan Kobrick, an engineer and human factors specialist who participated in a sevenmonth Martian simulation aboard a full-scale model HAB as part of the ongoing Flashline Mars Arctic Research Station studied the human factors element as part of his research. The rotating crews "play by the rules" of Martian life such as donning space suits when leaving the HAB, and simulating delayed communications with ground controllers, and he provides valuable information regarding crew interaction and success over time, physical effects of the simulation, and general observations/comments. Whereas the FMARS was designed as an initial temporary VTOL, the design of the simulation and parameters followed obey the NASA Mars Design Reference Mission. The findings and notes can be used to inform the design of the permanent modules and settlement. With these human factors identified, it is important to now list the secondary and more technical challenges that relate to the nature of this project.

1.3 Technical Challenges

The successful design of a permanent settlement on Mars requires not only resolving the critical human factors element, but also addressing the technical, engineering challenges. Engineers and architects must solve the challenges of transport and delivery methods, safety systems, environmental conditions, structural systems, and resource extraction/production Considering the exponential growth and development of technology, future solutions to this challenge will be more advanced than anything we can imagine today. Part of this thesis explores the potential for new and emerging technologies to aid in the design and construction of Martian settlements, but this section defines current conditions and capabilities.

1.3.1 Transport

Most designers today assume the rules established by the Mars Design Reference Mission, which says no single payload exceeding 60 tons and a maximum travel distance on the surface of Mars less than one kilometer, accomplished through the use of pressurized rovers. Parameters involving size limitations also are defined, with realistic projections applied to the use of inflatable structures. In this project, unmanned aerial vehicles (UAVs) will transport the components of the settlement when trajectories are ideal, and humans will arrive on separate crafts to minimize travel time and exposure in space. Operations on the Moon will have demonstrated and proven the viability of In-Situ Resource Utilization (ISRU), providing a virtually limitless supply of water, oxygen, and fuel. These processes will be applicable on Mars as well, and will greatly reduce the dependence on Earth for much of the basic supply needs of the inhabitants. Greenhouses and other vegetation/landscaping will provide nutrition, added psychological benefits, and a renewable supply of building materials and oxygen.

1.3.2 Structural

Whereas here on Earth engineers and architects address first the issue of how to make a structure stand up against the force of gravity, the first challenge of the designers for Mars is to determine how to keep a building "in." With an atmospheric composition roughly 1% the density of Earth's, the greater challenge Martian architecture faces is how to keep a pressurized structure from blowing out, or exploding, similar to a pressurized aircraft at high altitudes on Earth. The reduced Martian gravity of about 1/3e allows for a lighter structural design, but the idea of the architectural skin as a membrane takes an additional role in protecting the inhabitants of the pressurized enclosure. Much of the research and proposals being considered today for this kind of scenario involve the use of inflatable or telescoping structures, in conjunction with the use of rigid metal structures. These provide the greatest volume-to-mass ratios, and have proven to be a reliable means of enclosure. There are added benefits to these types of systems, both in terms of transportation, and simplicity/ease of construction. The danger inherent to an inflatable structure relates to its vulnerability to impacts from micrometeorites. While most of the objects that strike the Earth burn up in the atmosphere before striking the surface, Mars does not have this layer of protection due to its tenuous atmosphere. How the architecture of an inflatable dwelling affects psychology remains unexamined, and a key point in future research. For the purpose of this project, metal structures will serve as the living space modules and other life-support spaces critical to the survival of the settlement, with inflatable structures serving as circulation, greenhouses, and social spaces.

1.3.3 Environmental

With a known structural system, the next major technical challenge relates to radiation exposure. The flimsy Martian atmosphere does little or nothing to impede the flow of deadly charged particles bombarding the surface from all angles. There are three types of solar radiation humans must be protected against before ever occupying the surface for an extended stay- solar wind, solar flares (Figure 1.1), and galactic cosmic rays. The first two types, solar wind and solar flares, emanate from our Sun, and although somewhat random and unpredictable, can be prepared for. Direct solar observation and satellite telemetry will allow enough warning time to prevent direct exposure to the inhabitants via the use of extra-shielded spaces during SPEs (solar particle events). Unfortunately though, galactic cosmic radiation comes from exploding stars at all points in the universe and is not as predictable. However, the best choice of site would include one that minimizes solar exposure while still providing view, exploits existing topography, protecting the occupants by natural landforms while providing direct access to geological significant and varied strata, and natural resources (Figure 1.2).

The lack of an atmosphere creates the need for a completely sealed pressurized environment. The mean atmospheric pressure at sea level on Earth is 1013 millibars, while the

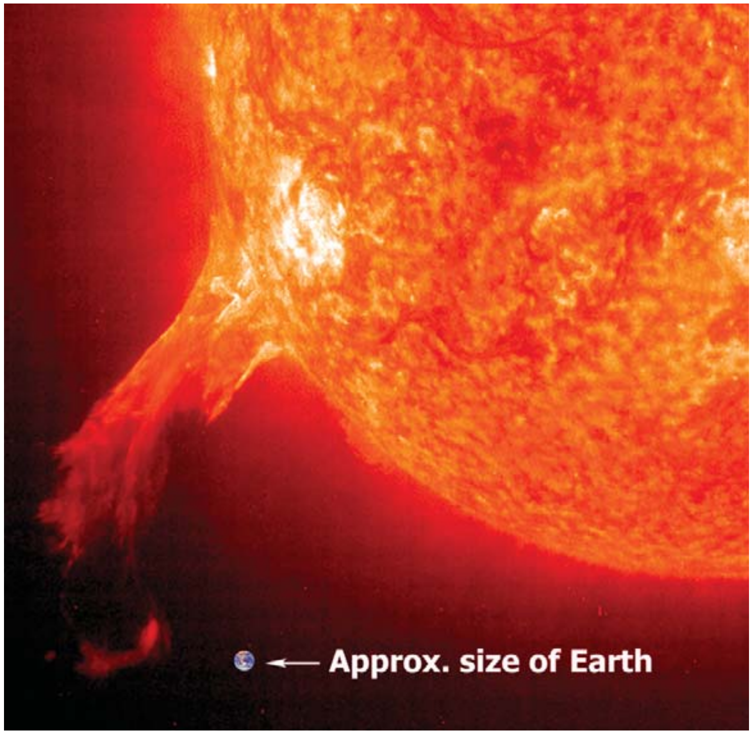


Figure 1.1 Solar flare

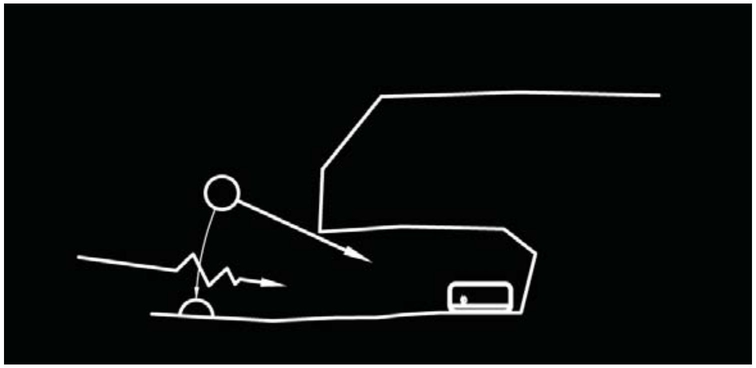


Figure 1.2 Site protected by overhang

pressure at the highest permanently occupied civilization at Mt. Potosi, Bolivia averages 620 mb. Rather than pressurize the settlement to the full 1000 mb, the settlement can be maintained and occupied at this level without any adverse side effects (Petrov 2004). The atmospheric pressure on Mars ranges from just 1 mb at the summit of Olympus Mons to 10 mb at the floor of Hellas Planitia (Figure 1.3).

As on Earth, the lower the elevation, the greater the atmospheric pressure, and this relationship gives reason to locate the settlement at a relatively low elevation. Doing this will minimize the pressurization gradient between the interior and exterior, and will take advantage of any future terraforming efforts. The dangers involved with the pressure gradient will play a defining role in the structural design of the individual modular components.

Mars is a much colder planet than Earth, located approximately 50% further away from the Sun than the Earth. With an average surface temperature of -60C, the conditions are more inhospitable than Antarctica. The temperature does range considerably, with records of 20C measured near the equator (Petrov 2004). These extreme temperatures and lack of atmospheric pressures require systems and designs that are completely safe, with double and triple-redundancy measures in place in the event of a failure. The settlement must be extremely well-insulated and take advantage of the greenhouse effect to retain and reuse heat. Covering parts of the settlement with the Martian regolith, or dirt is a potential insulating option that has been proposed in

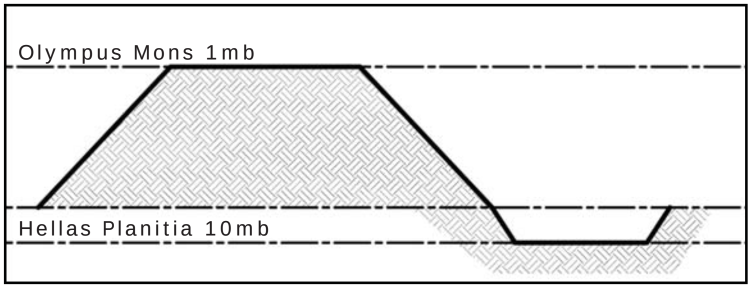


Figure 1.3 Elevation vs. atmospheric pressure

previous studies. Dust storms are also a frequent occurrence on Mars, often enshrouding the entire planet for months (Figure 1.4) and the design must take this into consideration. Solar power generation/visibility is extremely reduced during the storms, thus the scheme will incorporate wind power generation as well as solar power, and all exposed materials will be abrasion resistant.

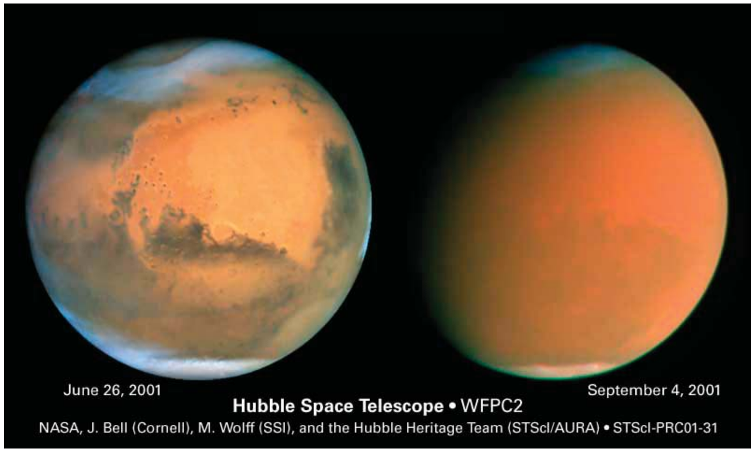


Figure 1.4 Martian dust storm

2. BACKGROUND

From the time early astronomers first looked at Mars through telescopes in the seventeenth century, people have been fascinated by the idea of the red planet as a potential home away from Earth. The Apollo missions in the 1960s opened imaginations to the very real possibility of exploring and settling on Mars. Since then, robotic spacecraft have returned an immense amount of information about our solar system, and the technology being developed today will enable us to occupy the Moon and Mars. As was briefly described earlier, the reasons for choosing Mars for this project are numerous and obvious. In reality, it is the only viable candidate for settlement that we can reach with current technology. Mars is the most similar planet to Earth when comparing gravity, temperature, and compositional makeup. While Mars has a diameter of just more than half of Earth (Figure 2.1), it has almost the exact amount of dry land, an abundance of material resources, and perhaps most importantly, a Martian day is almost the same length as a day on Earth (Figure 2.2). This fact will allow people to grow plants which will provide food, oxygen, and material resources, greatly reducing dependence on Earth. Because of the lower overall density of Mars compared to Earth, humans there will experience only 38%

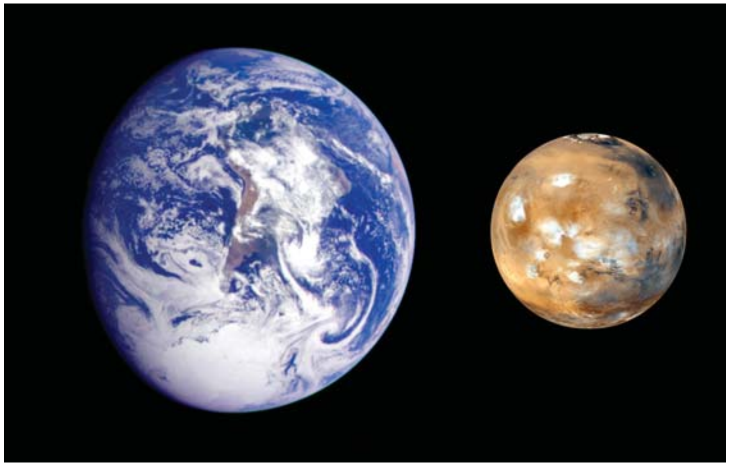


Figure 2.1 Mars/Earth Comparison

	MARS	EARTH
Diameter	4,220 miles	7,926 miles
Mass (10^24 kg)	0.6419	5.917
Distance from Sun	128-155 million miles	91-94 million miles
Atmosphere	7 - 9 millibars; 95% CO_2, 3% N	1014 millibars; 77% N; 21% O_2
Magnetic field	Extremely weak	Strong
Axial tilt	25.19°	23.45°
Revolution period (year)	687 days	23 hours 56 minutes
Rotation period (day)	24 hours 37 minutes	23.9345 hrs
Orbital eccentricity	0.093	0.017
Surface gravity	3.69 m/s^2	9.78 m/s^2
Escape velocity	11,185 mph	25,055 mph
Temperature range	-194° to +72° F	-27° to +136° F
Average temperature	-81°F	+57°F
# of Moons	2	1

Figure 2.2 Mars/Earth Comparison

of the gravity we are accustomed to here on Earth. Unfortunately though, construction is not any easier on Mars, due to the forces involved with the pressurization difference. Mars has an axial tilt of 25.10°, very similar to Earth's 23.45° and as such, experiences seasons like on Earth, from which should benefit the settlers psychologically. Temperature (distance from the Sun) was another deciding factor in the selection process. Mars is a much colder planet than Earth. On average it is 1.5 times further from the Sun than Earth. Although environmental conditions on Mars are more inhospitable to humans than those in Antarctica, it still remains a virtual paradise compared to the next planet closer to the Sun, Venus (average temperature of almost 800°F, atmospheric pressure equal to 93 times that of Earth, and clouds of sulfuric acid). Extremely efficient insulating materials will be critical for preserving the interior heat of the pressurized spaces on Mars, and can be expected to be developed over the next few decades. The availability of water as a resource for drinking, as well as providing hydrogen for fuel and oxygen to breathe is the most important resource necessary for extended human survival on the Martian surface. New data shows more water on the Moon than was previously believed, and the NASA Mars Exploration Rovers & the Mars Reconnaissance Orbiter have determined that liquid oceans once covered much of the surface, and vast amount of that water remains as frozen water ice at the poles (Figure 2.3). Ground penetrating radar and satellite imagery continues to reveal new reserves of water/ice as glaciers buried beneath the surface layer of Martian dust, or regolith (Figure 2.4).

Figure 2.3 Water ice at north pole

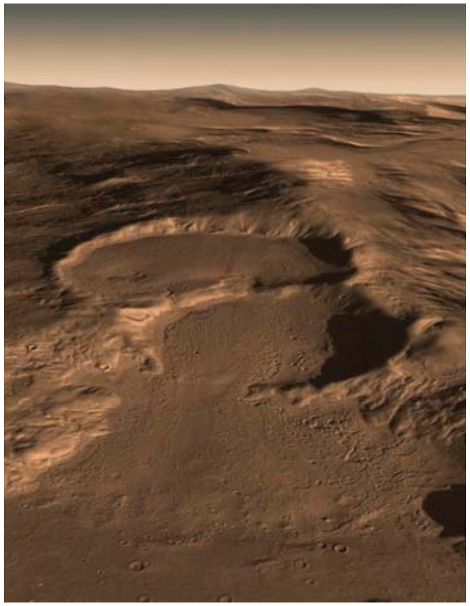


Figure 2.4 Glaciers beneath regolith

The final reason for selecting Mars in this project relates to the understanding of our own origins and the evolution of Earth. As we now know Mars was once a much warmer, wetter place, and is the prime candidate for our search for life in this universe beyond Earth, extant or extinct. The geological study of its history will shed new light on the knowledge of Earth's past, present, and future.

2.1 PRECEDENTS

The idea of travelling to and living permanently on another planet should come as no shock or surprise to the reader of this document. Human progress and evolution has been marked by our natural desire to explore new environments and to inhabit and manipulate the environment around us. We now occupy every continent, the air, and the sea. For some, the trip to Mars and the very thought of living there may be outside the realm of possibility. However, a convincing argument is found looking at the precedents in history which have led us to the present juncture we now face.

When Christopher Columbus sailed from Spain in 1492 in search of a western passage to the Indies, the world incorrectly thought the Earth was flat. Possessed by our inner human nature to explore, Columbus managed to acquire and man three ships on a voyage many surely thought was a suicide mission (Figure 2.5). The myth that the Earth is flat was enough to deter people from crossing the oceans for thousands of years. The crews of The Nina, The Pinta, and The Santa Maria were out of sight of land for months, and faced many similar conditions that the first humans will endure on the way to Mars. They depended on the design and durability of their ships, survived off a limited supply of food and water, and lived in cramped and close quarters. They also faced several challenges and potential dangers the first crews to Mars will not have to endure, such as an unknown path or voyage duration, spoilage of food, unforeseen storms, and poor sanitary conditions. In many respects, the first travelers to Mars will have an easier voyage psychologically and physically than the first who crossed the Atlantic Ocean.

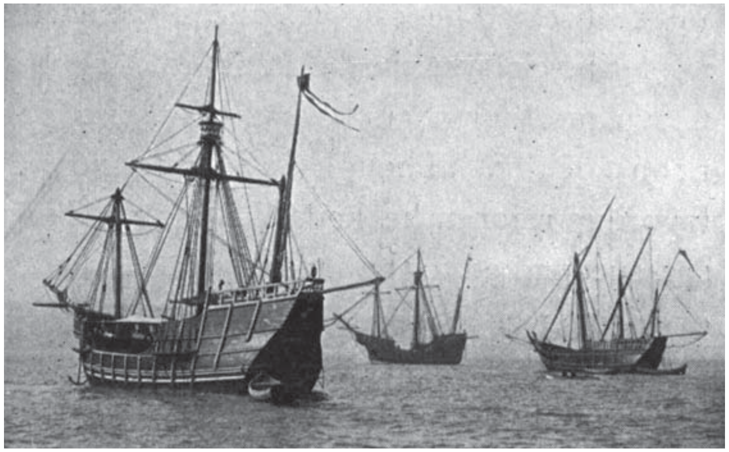


Figure 2.5 Spanish explorers

The crews of the first polar bases and submarines are among the next group of precedents to be studied. These explorers were the first to inhabit extreme environments, similar to those that the first settlers on Mars will experience- in places where simply stepping outside unprotected or any structural failure results in death. The success of these facilities demonstrates the potential for designing habitats in extreme environments. The occupants in these cases face similar claustrophobic conditions, limited views to the outside, remoteness, isolation, and the constant threat of danger from external conditions. The advantage that the future Martian settlers will have over this group of people includes the research that was gained from the success and failures of these precedents, especially in the area of human factors. These groups represent the first semi-permanent settlements in extreme environments, and highlight the need for individual private space, and views to the outside.

Astronauts are the final group of precedents to be compared to the first permanent settlers on Mars, and specifically those who travelled to the Moon and lived aboard Skylab, Mir, and the International Space Station (Figure 2.6). These explorers faced many unknown challenges, dangers, and obstacles becoming pioneers in the final frontier of space. Their expeditions and voyages provided information and knowledge about the physiological and psychological responses to being in reduced and/or microgravity. Escaping the Earth's atmosphere has allowed studies of radiation and microgravity and its effects on human physiology and psychology. The first permanent settlers will have the benefit of knowledge gained from all of these experiments, as well as everything learned from missions between now and the time of this project in the year 2050. Future lunar and Mars missions, both robotic and manned, will provide access to untold knowledge and technology benefitting and aiding the design of space architecture in the solar system and the first human settlers on other worlds.


Figure 2.6 Apollo Moon landing

2.2 CASE STUDIES

The process of analyzing similar projects for their relevance as case studies provides insight into the areas where research is missing or needed. Three projects or proposals were selected for analysis due to their similarity of this investigation, and are the *The Surface Extreme Environment Dwelling System for Mars* by Kurt Micheels (USF 1994), the HAB module concept designed by Robert Zubrin (1995), and *A Permanent Settlement on Mars: The First Cut in a New Frontier* by Georgi Petrov (MIT 2004).

2.2.1 The Surface Extreme Environment Dwelling System for Mars (S.E.E.D.S.)

S.E.E.D.S. is a graduate architectural thesis involving a semi-permanent deployable Martian habitat for six people (Figure 2.7). The design includes expandable spaces and other separate components that are attached as the surface habitat "unfolds" (Figure 2.8) and appears to be based entirely on existing technologies.

Structurally the project consists of a combination of rigid and inflatable structures. Particular attention was paid to the mechanics of the habitat and maximizing the economy and usefulness of personal spaces. In terms of sustainability, the project does not address the idea of food production and was not included in the research, but does include a plan for deployable solar arrays on top of the structure to provide electricity. The decision to omit greenhouses for food production is valid and likely for the initial, short-term missions to Mars, provided sufficient reserves of consumables. Architecturally, the design appears to have little social space. Circulation is kept at a minimum, and there is a lacking hierarchy of space (Figure 2.9). Much of this criticism is the result of the compactness of the all-in-one design of a vertical take-off and lander (VTOL) given today's rocketry limitations, and the design intent This being one of the earliest serious proposals involving Martian architecture, Micheels conceives of many critical aspects of the design for any Martian structure. Important to this project, he includes the provision of private sleeping spaces. Because personal space is designed at an absolute minimum of approximately 49SF per person (Figure 2.10), it is perhaps insufficient for permanent occupation. Assuming an 8 foot ceiling height, this personal space is very close to the minimum threshold of 400 cubic feet per person for human occupation as defined by NASA design standards (Figure 2.11). There is also a centrally located shielded refuge core

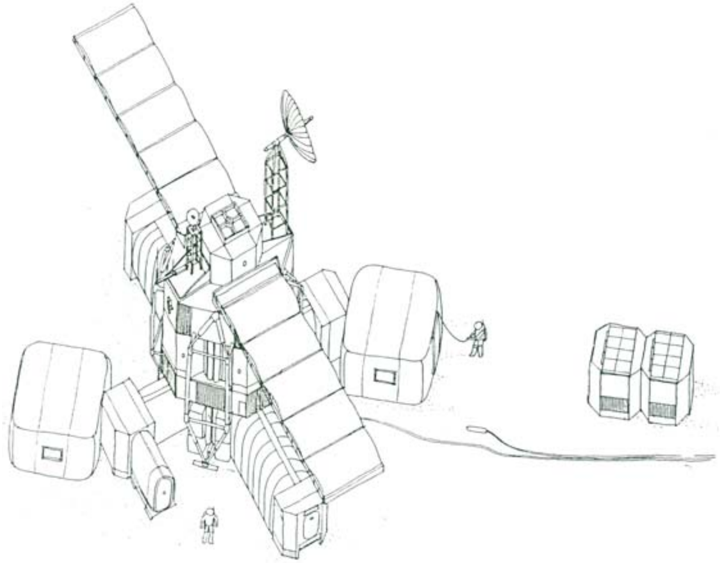


Figure 2.7 S.E.E.D.S. fully deployed

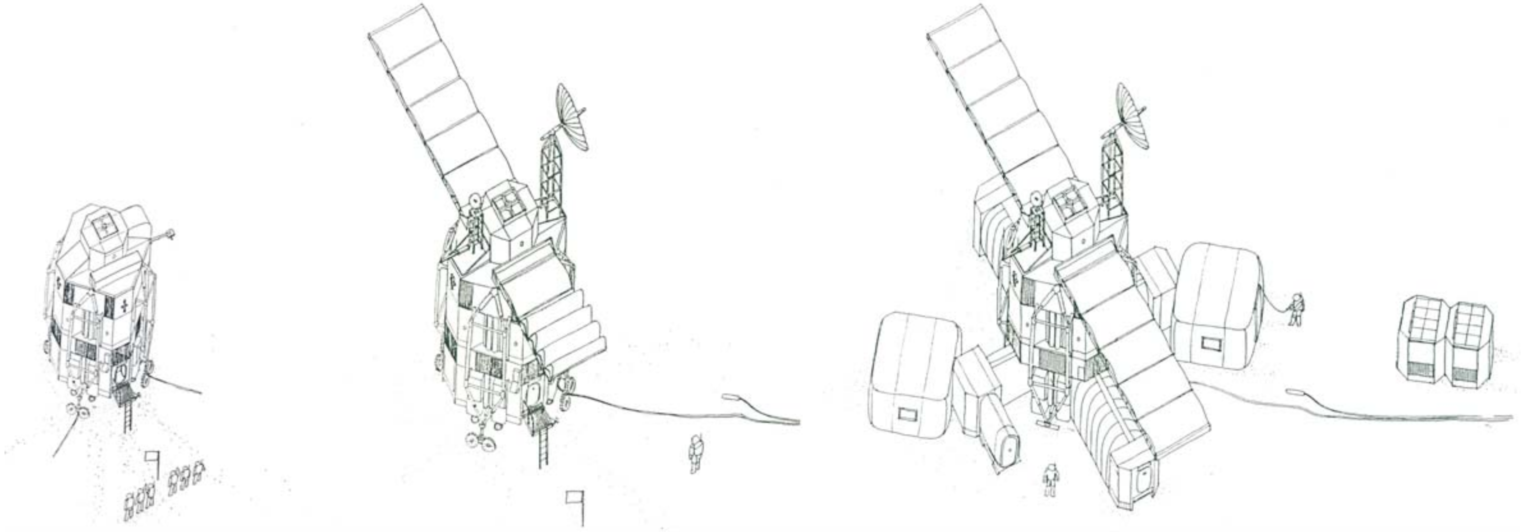


Figure 2.8 S.E.E.D.S. deployment

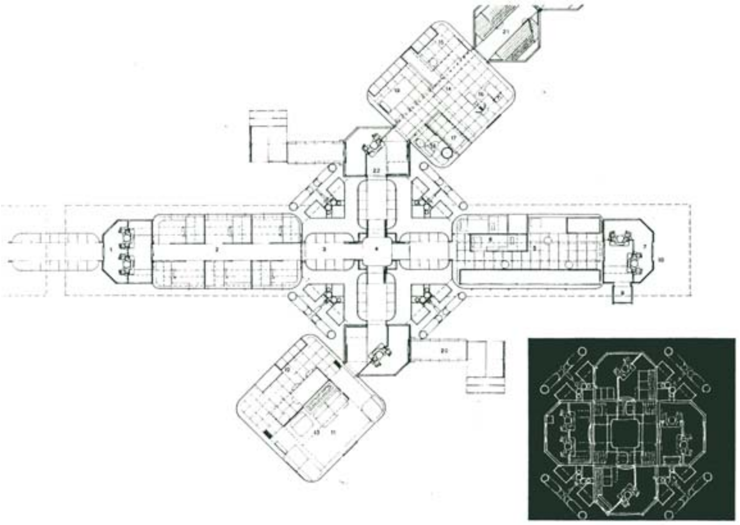


Figure 2.9 S.E.E.D.S. floor plan

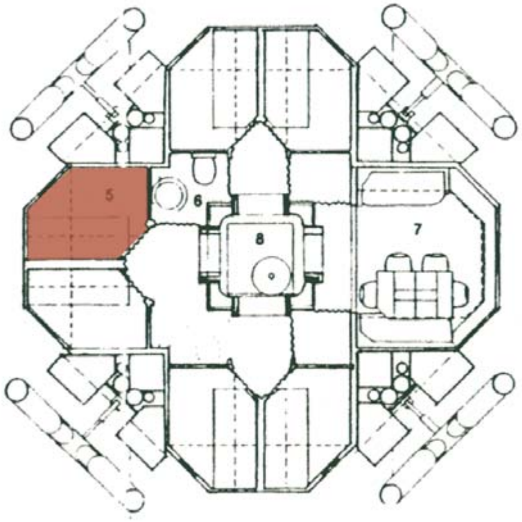


Figure 2.10 S.E.E.D.S. personal living space

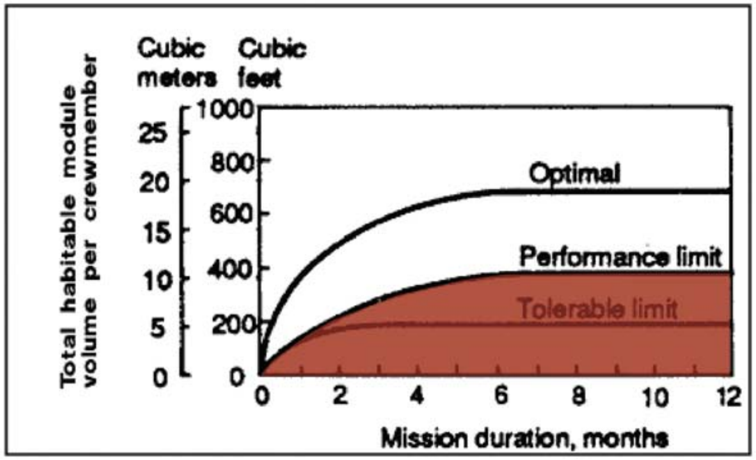


Figure 2.11 NASA personal space standards

for use during solar flares, and an identified "recreation module." Permanent settlers will need a larger amount of recreational or entertainment space than on Earth, due to the impossibility of stepping outside without a space suit. To mitigate against claustrophobia, boredom, and muscular/skeletal atrophy, ample space must be allotted in any permanent settlement on Mars for entertainment, recreation, and exercise. In summary, this design could potentially serve as a temporary or semi-permanent habitat, but given the tight spatial conditions, may prove to be inadequate for long-term or permanent occupation. The complexity in the deployment will prove to be technologically outdated by the year 2050, but appears to be possible with today's technology. Unlike SEEDS, the permanent settlement being proposed here seeks to take advantage of emerging technologies that will be developed before people settle permanently on Mars. The identification and need for personal and entertainment spaces was essential to the success of this project, and must be employed in any Martian habitat.

2.2.2 HAB Module

Originally designed by Robert Zubrin, the "HAB" Module is the second case study and involves the most extensively considered plan for the first trip to Mars. Conceived of as a sort of "tuna can," it was designed by Zubrin in the 1990s in response to NASA's incredibly expensive plan and dramatically reduced the estimated cost of the first trip to Mars. The plan, originally called "Mars Direct," involves sending the return craft and chemical plants that manufacture water and fuel for the return flight from the Martian atmosphere to Mars years in advance of people. Eliminating the weight of the fuel and water from launch from Earth was the key idea and economic genius behind the concept, and much of his plan has been incorporated as part of NASA's 1997 Mars Reference Mission. Similar to Micheels' proposal, Mars Direct also involves a VTOL surface habitat for six people, in a semi-permanent setting (Figure 2.12).

The plan appears to be technically feasible today, and many advocates for the voyage to Mars are in favor of cancelling plans to return to the Moon first, in favor of going directly to Mars now. Structurally, the design is simply a rigid metal cylinder can that contains all of the spaces necessary for semi-permanent habitation of Mars. The basic design of the

Figure 2.12 NASA Mars Reference Mission

Figure 2.13 Flashline Mars Arctic Research Station

HAB was used in the construction of the Martian simulation study *Flashline Mars Arctic Research Station* (FMARS) where researchers simulate the living conditions on Mars (Figures 2.13, 2.14). The personal space in this design is identified and calculated at a more generous and comfortable 79SF, including a place for sleep and a small work area (Figure 2.14). The plan provides, an absolute minimum space for social activities with a small dining table(Figure 2.15). Considering the nature of this project as a serious proposal for the first voyage to Mars, and the relative short-term occupation of the HAB, the design is more than likely to be suitable for its intended purpose.

Figure 2.14 FMARS interior rendering

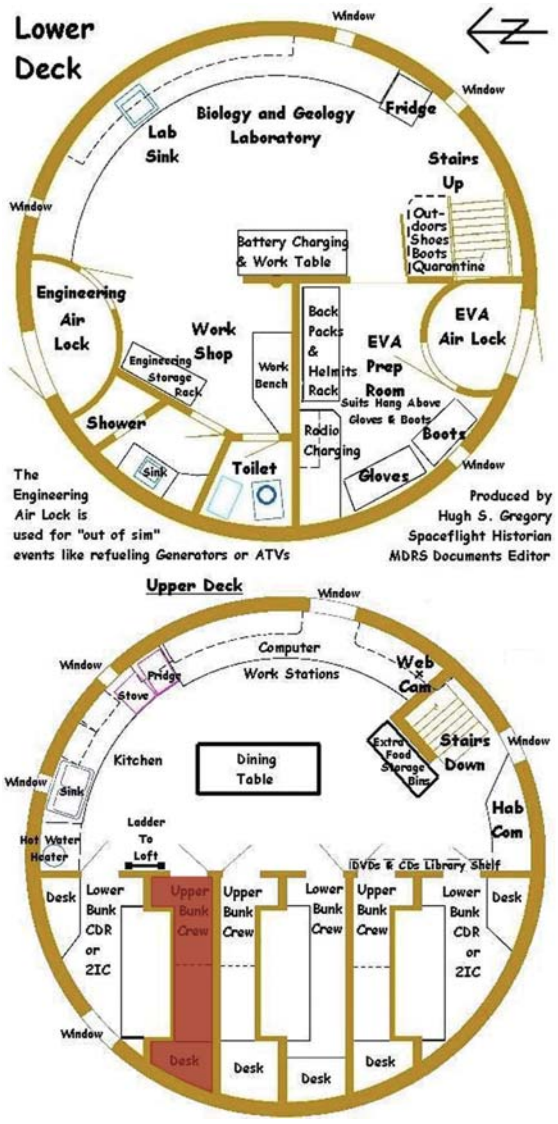


Figure 2.15 FMARS floor plans

2.2.3 A Permanent Settlement on Mars: The First Cut in the Land of a New Frontier

The third and final case study is another architectural thesis by Georgi Petrov. This is the most recent project examined, and similar in focus and scope to this thesis. Petrov designed the first permanent settlement to accommodate 100 Martian settlers (Figure 2.16), and was the first to identify the living space module as an individual modular component (Figure

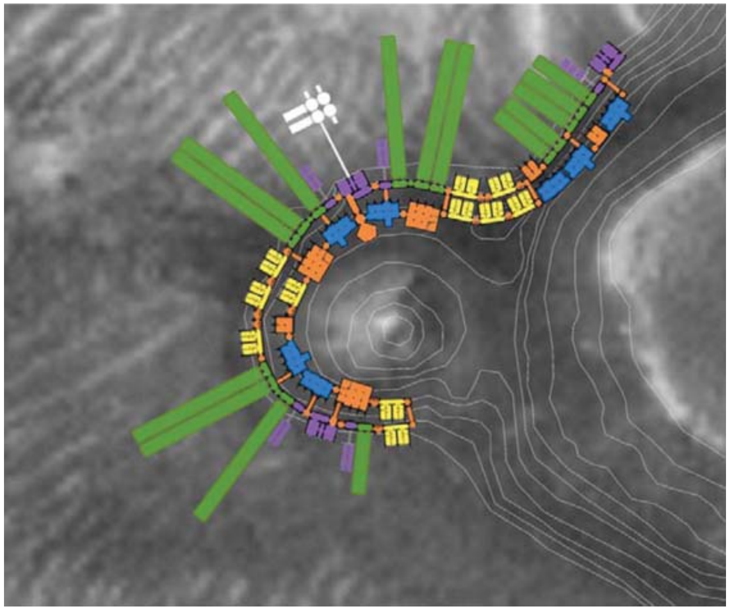


Figure 2.16 Masterplan, Petrov

Figure 2.17 Private Quarters, Petrov

2.17).

The project is described well in terms of programmatic elements, construction techniques, and a phased expansion. Petrov uses a combination of new and existing technology with minor speculation involving a few aspects, including inflatable structures, food production techniques, and construction methods. This project employs resource utilization within the structural sytem by proposing a combination of rigid structures, inflatables, and brick masonry vaults covered with Martian regolith to resist the internal pressure of the settlement. Petrov focused on the 24-person first phase of the settlement as a prototypical module of expansion for the rest of the settlement, with the completed settlement described at a masterplanning level of detail. Vegetation plays a major role in this project, both in terms of human factors and for food production, with an area of approximately 1075SF allotted per settler. Most of the settlement is subterranean, covered by meters of Martian regolith and rocks.

This condition, besides being incredibly labor-intensive, will have negative psychological and physiological effects upon the inhabitants. Human beings are not designed to exist in subterranean environments, and closed, isolated and cramped habitats produce claustrophobic effects. Research shows that our eyesight adapts in these conditions, and people lose the ability to focus on distant objects when views to the outside are not present. One of the many strengths of the project is the combination of spaces to create a greater perceived volume. Petrov combined an open linear laboratory dedicated to growing trees and bamboo that provide oxygen, food, and materials with the primary circulation space and shared social spaces to create a double-height “green belt” that provides natural relief in this extremely sterile and hostile environment (Figure 2.18). Natural light is captured via skylights and mirrors above, but may not compensate for adequate access to views outside (Figure 2.19). The project is also the first to define the

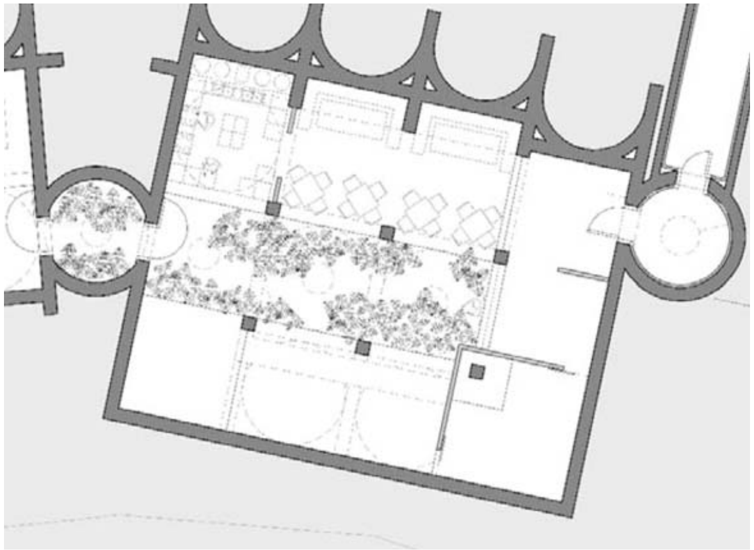


Figure 2.18 Social spaces/laboratories, Petrov

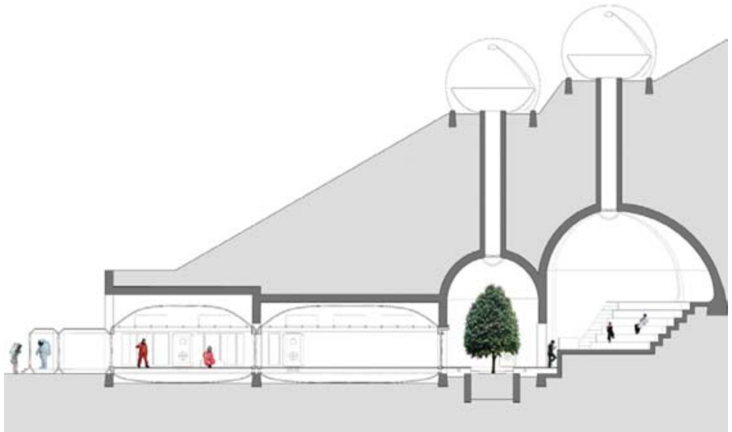


Figure 2.19 Site section, Petrov

personal living space as a more livable, private module. Both single-person and two-people living space modules are identified as providing about 270 SF of private space per person (Figure 2.20), realizing the need for increased space that comes with permanent habitation as opposed to short-term or semi-permanent plans. Although the living space module was well defined structurally, the plan is schematic and more attention to detail is necessary as this spatial module is identified as the most critical component to the overall success of the first permanent Martian settlement and this thesis. The exact spatial configuration, volumetrics, life support systems and safety systems of the living space module will be of specific interest to this project to best facilitate extraterrestrial habitation.

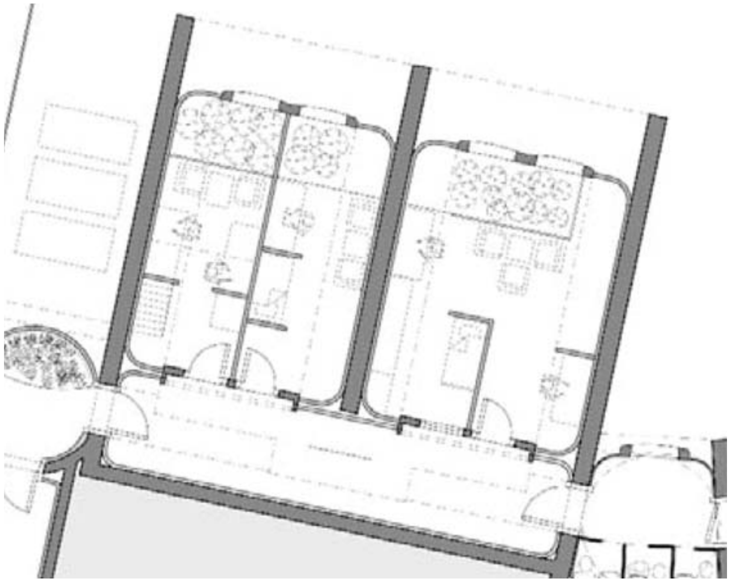


Figure 2.20 Private quarters floorplan, Petrov

2.3 Emerging Technology

The profound advancements we have developed in the last century radically altered our way of life, allowing us to escape the gravity of Earth and explore worlds beyond our own. History has shown, and most futurists agree that this “change” in technology is accelerating at an exponential rate, and will continue for the foreseeable future. Even Moore’s Law, historically thought to as linear, is trending upward exponentially (Figure 2.21). Developments being made in computing, material sciences, medicine, robotics, nanotechnology, architectural skins, microelectromechanical systems and programmable matter among many others will lead to the technological singularity, the point in time in which the rate of growth in technology exceeds human comprehension and appears infinite. Futurists such as Raymond Kurzweil predict the singularity will occur near 2050, coinciding with the target date for this permanent Martian settlement. Unlike other Martian proposals, this thesis has a specified date in the future, and aims to study and benefit architecturally from these future developments. Three key areas identified in this project where future technologies can benefit the architectural design and construction are the following: architectural skins as membranes, nanotechnology, and programmable matter.

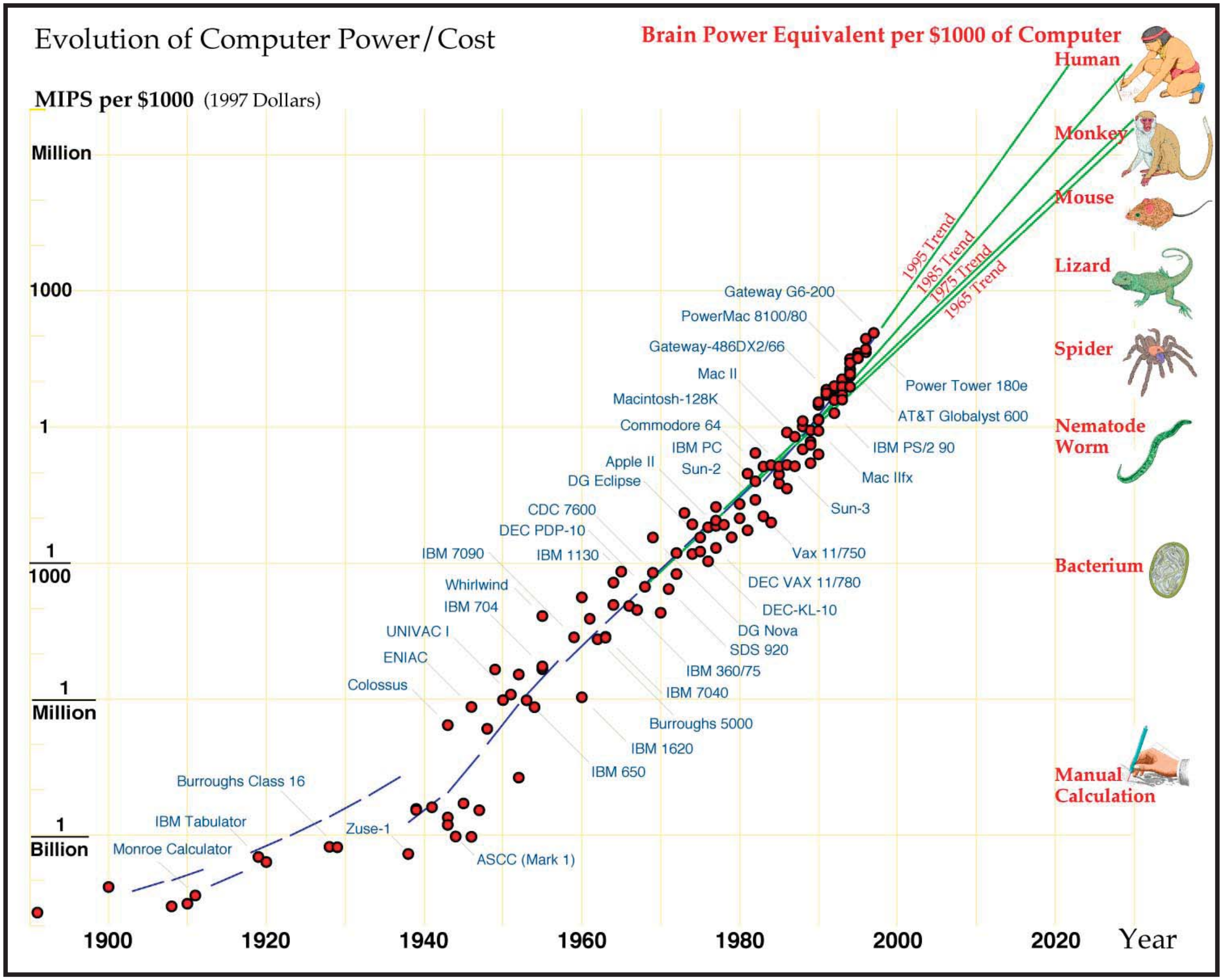


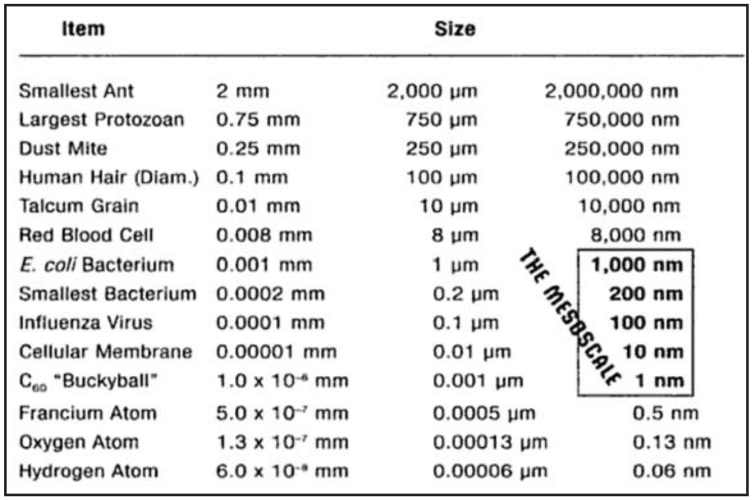
Figure 2.21 Moore's Law, Carnegie Mellon University

2.3.1 Nanotechnology

Nanotechnology - the ability to understand and control matter with ultimate precision - is the most powerful and enabling technology humankind has ever developed. "Nanotechnology is used to create materials, devices and systems with fundamentally new properties and functions that will change the world as we know it" (Cornell University). The development of nanotechnology holds the very real possibility of bridging the gap between the present and the technological singularity. The apparently simple concept of grasping the microscopic scale of nanotechnology is in reality, extremely difficult, if not impossible for our minds (Figure 2.22). The implications of nanotechnology and microelectromechanical systems are widespread, in fields ranging from science and medicine to computers/electronics, as well as architectural building systems.

The study of medicine and robotics is driving much of the present research and development of nanotechnology, and the potential architectural implications appear to be largely unexplored. Microscopic robots and machines will soon revolutionize the way medical procedures are conducted through non-invasive techniques that deliver drugs, targeting specifically infected cells and diseases, limiting damage/trauma to the affected areas (Figures 2.23, 2.24). These microelectromechanical devices, or MEMs are, "The integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology" (www.memsnet.org). The scale at which researchers and designers are operating and fabricating these devices is constantly shrinking and is approaching the nanoscale. Considering present capabilities of robotics, computing, and nanotechnology, it is not a huge leap of faith to predict that nanoscale machines will be able to, mine raw materials, transport them to building sites, and assemble building components at the molecular level, and even self-replicate by the year 2050.

Carbon nanotubes are the strongest known material to man (Figures 2.25, 2.26). Pioneering work led by Ray Baughman at the NanoTech institute in 2000 showed a multi-walled carbon nanotube to, "Have a tensile strength of 63 gigapascals (GPa)- translating into the ability to endure weight of 6300 kg on a cable with a cross-section of $1 mm^2$" (New World Encyclopedia, "Carbon nanotubes"). This incredible tensile strength will make carbon nanotubes an ideal material for inflatable structures on Mars which will be subjected to considerable tensile forces. Future fabrics will weave these microscopic structures into layers of plastic producing extremely resilient and strong materials. Much of the theoretical debate about constructing a space elevator on Earth involves the use of carbon nanotubes to meet the enormous forces acting on such a structure (Figure 2.27).



Item	Size		
Smallest Ant	2 mm	2,000 µm	2,000,000 nm
Largest Protozoan	0.75 mm	750 µm	750,000 nm
Dust Mite	0.25 mm	250 µm	250,000 nm
Human Hair (Diam.)	0.1 mm	100 µm	100,000 nm
Talcum Grain	0.01 mm	10 µm	10,000 nm
Red Blood Cell	0.008 mm	8 µm	8,000 nm
E. coli Bacterium	0.001 mm	1 µm	**1,000 nm**
Smallest Bacterium	0.0002 mm	0.2 µm	**200 nm**
Influenza Virus	0.0001 mm	0.1 µm	**100 nm**
Cellular Membrane	0.00001 mm	0.01 µm	**10 nm**
C_{60} "Buckyball"	1.0 x 10^{-6} mm	0.001 µm	**1 nm**
Francium Atom	5.0 x 10^{-7} mm	0.0005 µm	0.5 nm
Oxygen Atom	1.3 x 10^{-7} mm	0.00013 µm	0.13 nm
Hydrogen Atom	6.0 x 10^{-8} mm	0.00006 µm	0.06 nm

THE MESOSCALE

Figure 2.22 The size of things, McCarthy

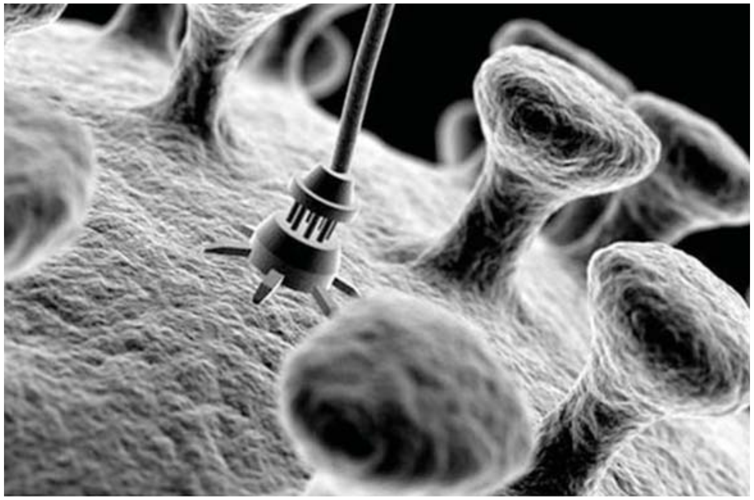
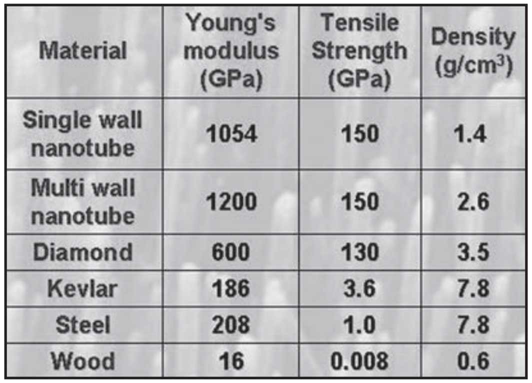


Figure 2.23 Conceptual MEMs device

Figure 2.24 Conceptual MEMs device



Material	Young's modulus (GPa)	Tensile Strength (GPa)	Density (g/cm³)
Single wall nanotube	1054	150	1.4
Multi wall nanotube	1200	150	2.6
Diamond	600	130	3.5
Kevlar	186	3.6	7.8
Steel	208	1.0	7.8
Wood	16	0.008	0.6

Figure 2.25 Nanotube Strength, Nanopedia

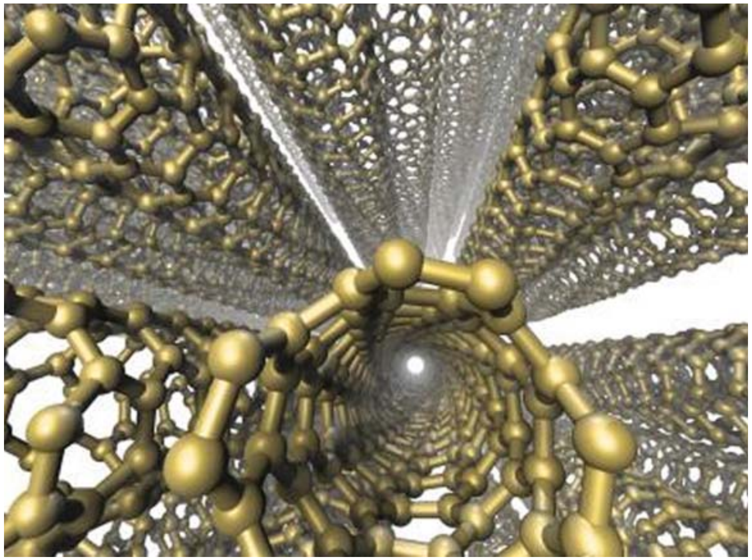


Figure 2.26 Nanotube structure

Figure 2.27 Space elevator

2.3.2 Programmable Matter

Programmable matter may revolutionize the way people think about and create everything. ”Any technology sufficiently advanced is indistinguishable from magic. And that’s what programmable matter is-it’s a technology so advanced it might as well be magic” (Arthur C. Clarke). Still in the conceptual and experimental phases, this shape-shifting technology is being spearheaded by the Defense Advanced Research Projects Agency (DARPA). The goal is to create, “A new functional form of matter constructed from mesoscale building blocks (“MesoParticles” up to 1 cm size), which reversibly assemble into complex 3D objects upon external command. These 3D objects will exhibit all the functionality of their conventional counterparts. Programmable Matter represents the convergence of chemistry, information theory, and control, into a new materials design paradigm, referred to here as “InfoChemistry,” building information directly into materials” (www.darpa.mil). The developers of programmable matter are working to create an, “Instant Toolkit,” a container holding an amorphous material that can be programmed to assume the form of virtually any tool, with all of the material strengths and qualities of a hammer, wrench, screwdriver, etc, and then returned to its initial form to be reused. A small, conceptual physical sample has been designed and is known as the, *Universal Rubik’s Cube* (Figure 2.28). Conceptually, this is similar to the “polymimetic liquid alloy,” behind the technologically advanced liquid metal T-1000

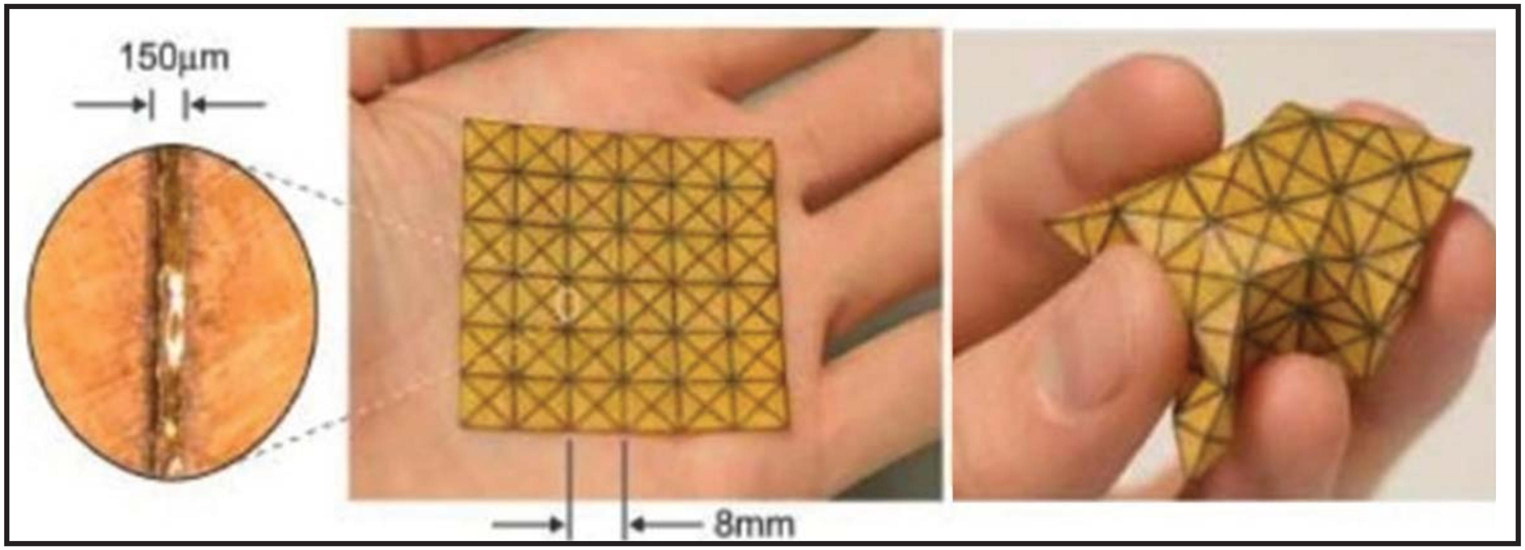


Figure 2.28 *Universal Rubik's Cube*, DARPA

terminator in James Cameron's science-fiction thriller *Terminator 2: Judgment Day*. In the *Artificial Symbiont* concept, Krulich Zbynek shows how mesoparticles can be assembled to create architectural structures using basic angle bisectors of tetrahedron (Figure 2.29).

The Claytronics Project being conducted between Carnegie Mellon University and Intel, "Combines modular robotics, systems nanotechnology and computer science to create the dynamic, 3-Dimensional display of electronic information known as claytronics" (http://www.cs.cmu.edu). The focus of this programmable matter project is on the following two objectives: to create the basic building blocks of claytronics, known as the claytronic atom or catom, and to design and write software that will program the shaping of millions of catoms into dynamic, three-dimensional forms (Figures 2.30, 2.31).

This merging of technology and the possibilities that this breakthrough entails appear to usher in the technological singularity. Whereas nanotechnology seems to be driven largely by research in medicine and robotics, programmable matter is being developed by defense research. However, the architectural implications are astounding. When the secrets of programmable matter are unlocked, the idea of "programmable space," becomes a reality.

In the future, structures constructed entirely from programmable matter will give the occupants the ultimate design control over their own spaces, structural systems, and building enclosures. Occupants will be able to configure and reconfigure their habitats as their needs and wants change over time.

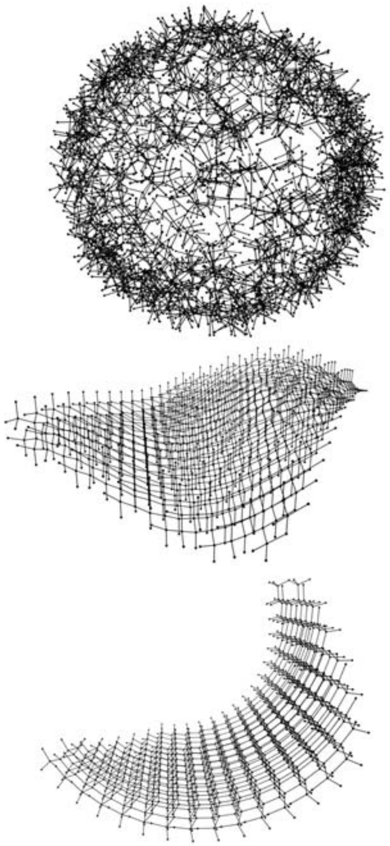


Figure 2.29 *Artificial Symbiont*, Zbynek

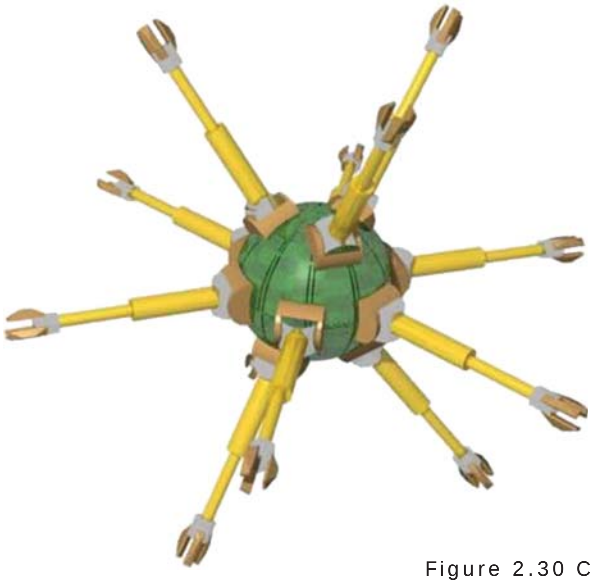


Figure 2.30 Catom

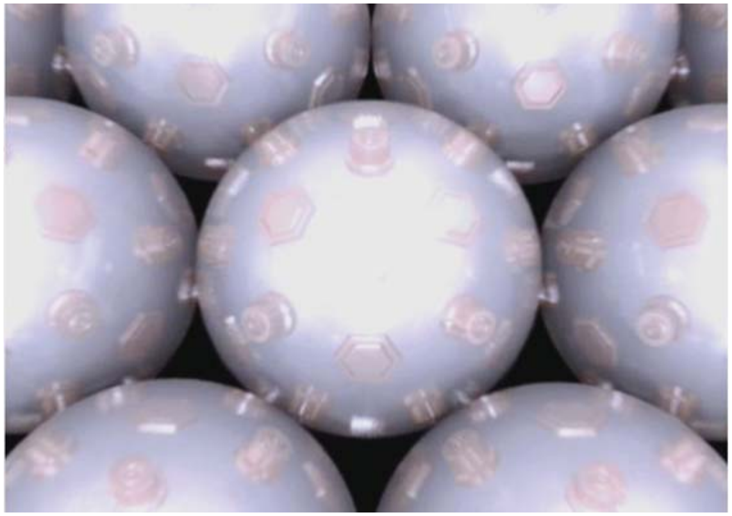
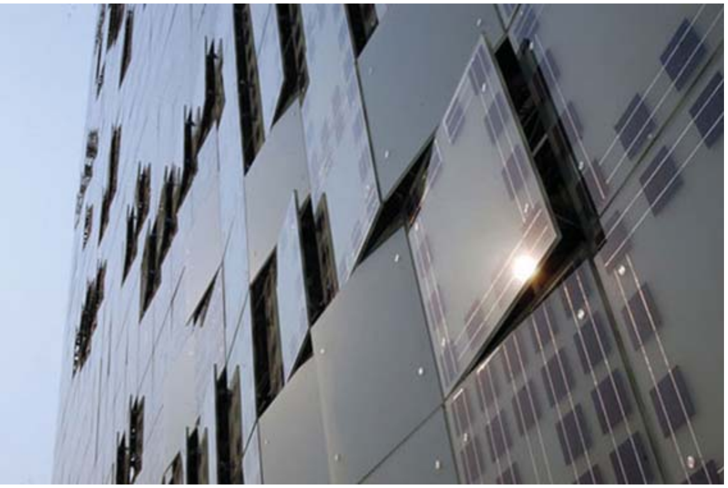


Figure 2.31 Claytronics

2.3.3 Building skins as membranes

Advances in architectural building skins and materials are transforming the way architects and engineers design building enclosures. A multitude of technologies are being integrated to create the next generation of building materials, which will benefit architecture on Earth and beyond. Buildings skins today are already programmable in one sense as they begin o embed technologies such as photovoltaic cells, LCD systems, and electrochromic glass into the design. The Greenpix zero energy-use media wall by Simone Giostra in Beijing is a built example, employing both photovoltaic and LCD technology into the glass façade of a large building to create an environmentally-sustainable dynamic and



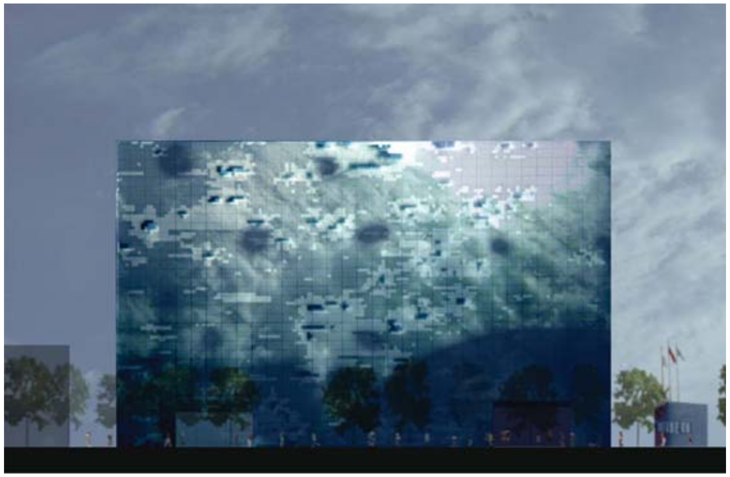
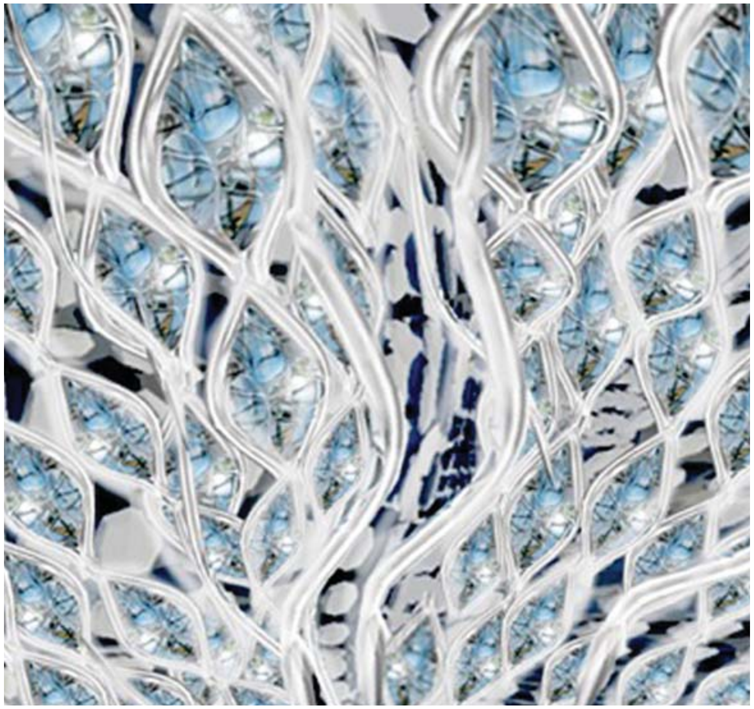


Figure 2.32 Greenpix, Giostra

interactive display (Figure 2.32).

Studio Formwork has developed a product called *Solarskin* for application to existing building exteriors. Solarskin is an inflatable foam and polymer structure with solar mirror parabolic ellipse collectors. (http://studioformwork.com). This modular system of panels forms watertight connections, and can be applied vertically or horizontally. Made from lightweight, affordable materials, this system provides shade/insulation to a building while producing electricity (Figure 2.33).



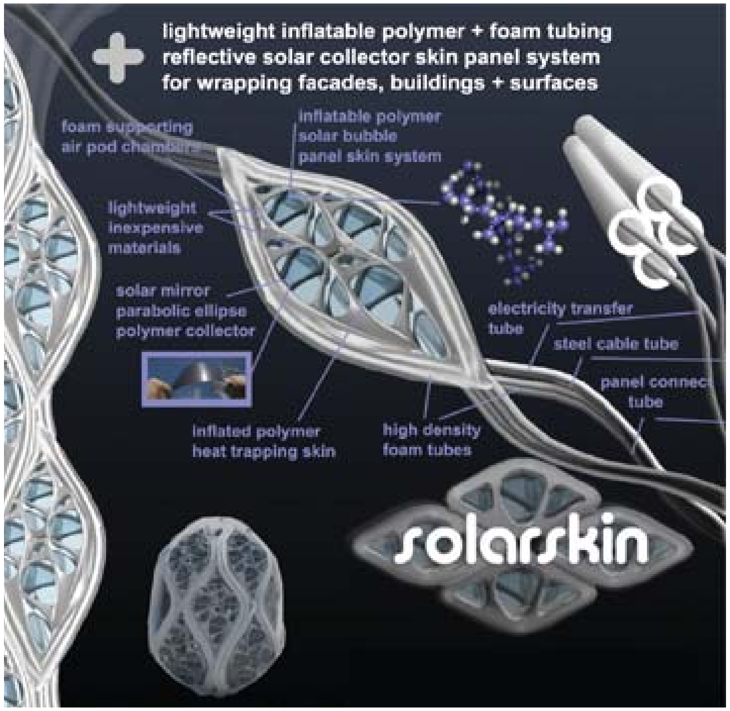
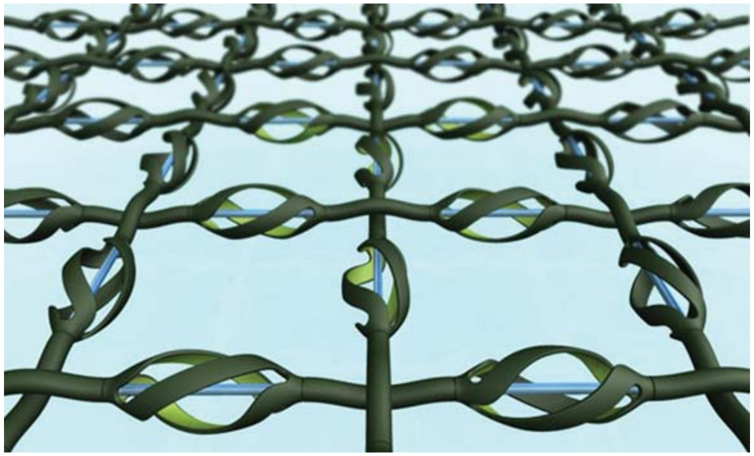


Figure 2.33 Solarskin, Studio Formwork

Designer Agustin Otegui has invented a living building skin called the *Nano Vent-Skin* employing several of these emerging technologies being described (Figures 2.34). It features micro-turbines that generate wind power, an exterior photovoltaic skin that generates solar power, and an interior skin of microorganisms that filter CO^2 from the atmosphere and produce oxygen (http://nanoventskin.blogspot.com). This integration of biological and non-biological systems is another premise and indicator of the impending singularity in the near future. The Nano Vent-Skin is another external skin system that can be applied to virtually any surface.



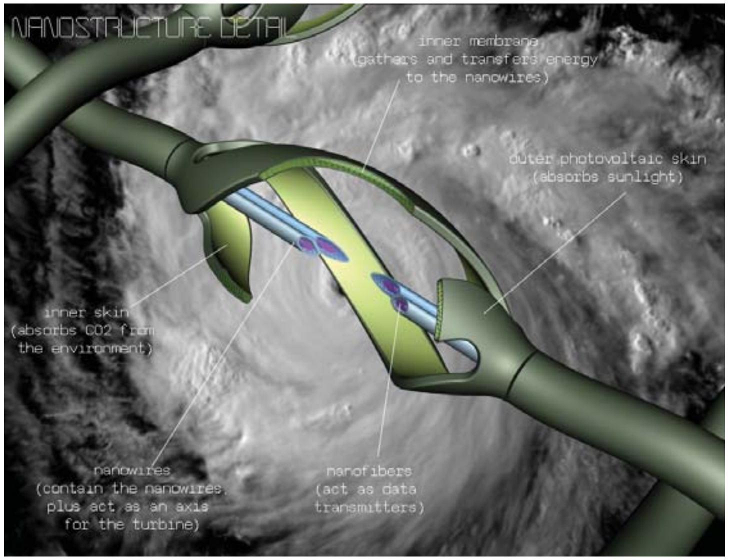


Figure 2.34 Nano Vent-Skin, Otegui

An analysis of all of these advanced proposals and designs reveals an emerging trend- that future building skins will employ multiple technologies incorporating sustainable design strategies. Considering the rate of growth in nanotechnology, programmable matter, and material sciences, it is probable that permanent Martian settlements built in the year 2050 will be radically different than anything being considered today.

3. SITE SELECTION AND ANALYSIS

The actual site chosen for the first permanent settlements on Mars will be based on a number of criteria, many of which remain to be studied by robots and humans in future missions. The exact site will need to provide access to resources, primarily water for the production of oxygen and fuel, proximity to geologic strata of scientific interest, relative ease of access from orbit, and protection from the harsh Martian environment if possible. In all probability and reality, the site chosen will be located in close proximity to the Mars Reference Mission to facilitate construction of the settlement utilizing existing infrastructure already on the surface. The location of the reference mission will be determined by robotic probes and rovers yet to be designed or sent to the planet, but must meet the basic site requirements described above. With so many confounding variables and unknowns, it is important to make some assumptions and decisions in order to select a real site on Mars for this project. This settlement is being conceived of as a prototypical model for the first permanent Martian settlements, and the theory and logic behind the modular approach is to allow for a range of configurations to adapt to different site conditions. The economy and reliability that comes with mass production is

Figure 3.1 Project location

necessary if humans are going to permanently settle on Mars.

The site chosen for analysis is near Husband Hill the area where the NASA Mars Exploration Rover *Spirit* (Figure 3.2) has been exploring for the last five years (Figures 3.3, 3.4). The reasons for choosing this particular area are numerous. First, the area is one of the most well-documented because of knowledge gained from Spirit and has a historical link to our understanding of Mars. It is the most logical Plymouth Rock on Mars in the year 2009. Since arriving on the Martian surface in 2004, Spirit has traversed more than 4 miles on the surface, taken thousands of photographs, performed countless experiments and measurements, yielding conclusive evidence of a warmer, wetter past. Hi-resolution imagery gained from the Mars Global Surveyor provides detailed contextual and topographical information. Evidence found by Spirit suggests ancient salty oceans once covered the surface, which could mean the present existence of

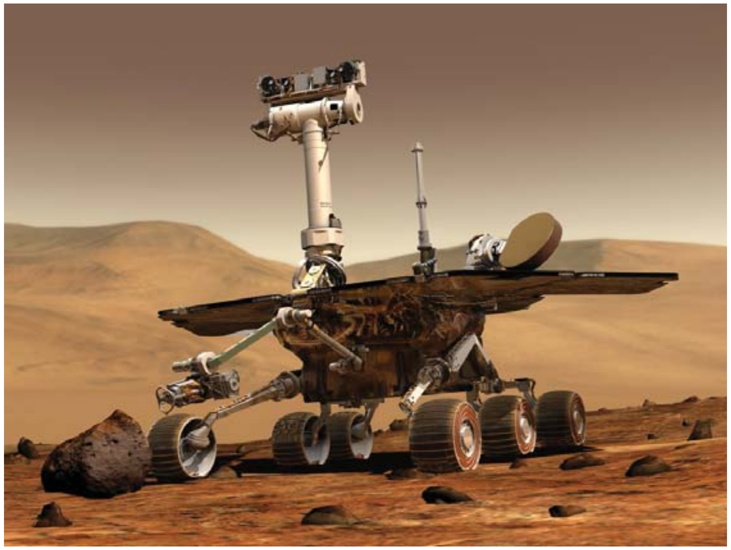


Figure 3.2 Spirit, NASA

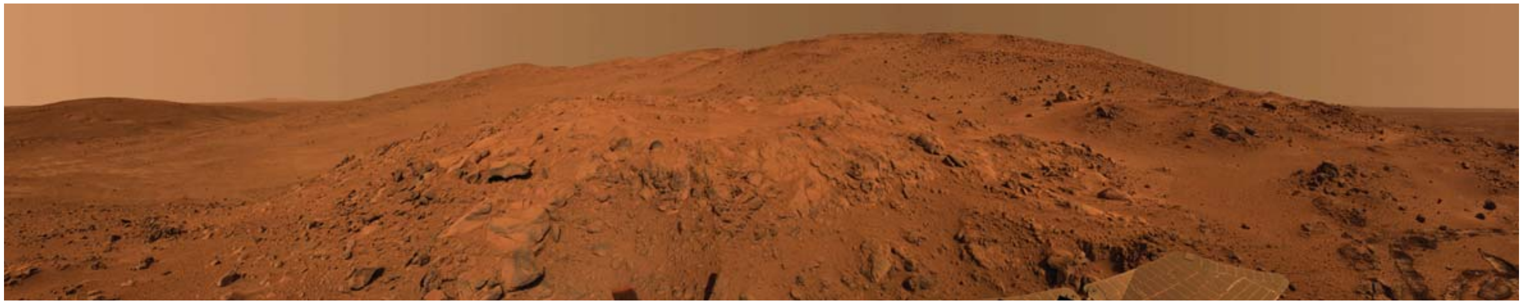


Figure 3.3 Husband Hill panoramic

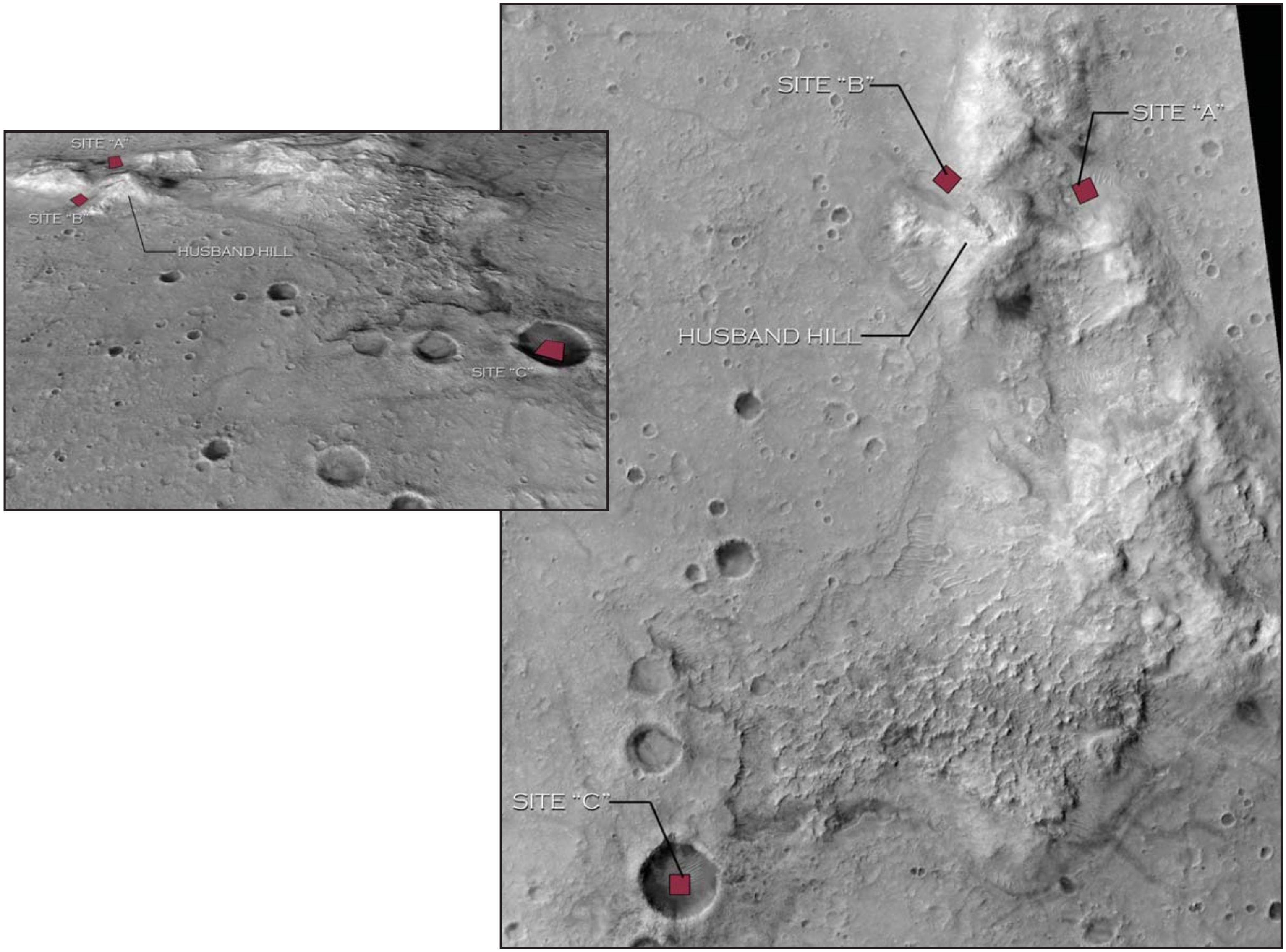


Figure 3.4 Site selection (photograph by NASA)

subterranean water or water ice. Water is the key to life as our definition currently holds, and will is the key resource necessary for sustainable human habitation on any planet, moon or asteroid. From it, both oxygen and fuel (H2) can be produced. Water will also be needed for drinking, agricultural production, and for HVAC needs. Much research is being done on Mars regarding the presence and location of water, and the estimates are constantly increasing as ground penetrating radar detects the possible presence of massive glaciers at latitudes even approaching the equator. It is assumed for this project that an ample supply of water for 100 settlers can be mined from beneath the ground for hundreds of years.

A near-equatorial site is important for several reasons. First, as on Earth, it is easier both to access from orbit and launch from the surface with a reduced gravitational field. Also, the general area chosen has a relatively low elevation of -6300’ below the datum and would benefit from a stronger atmosphere and early results of any terraforming efforts. Because Mars has a similar orbital tilt to Earth, the equatorial regions also have the advantage of being the most temperate part of the planet. Three individual sites near Husband Hill were selected for analysis as a potential site for the settlement.

Sites “A,” “B,” and “C” were identified for analysis based on primary evaluation criteria of differing sectional qualities which afford varying levels of natural protection from the elements via existing topography. Site A sits between two hills and is open to the other two sides (Figure

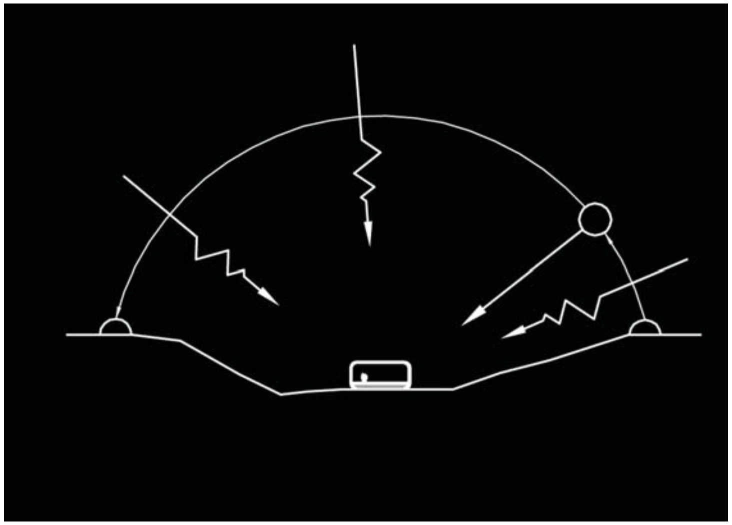


Figure 3.5 Sites A & C exposure

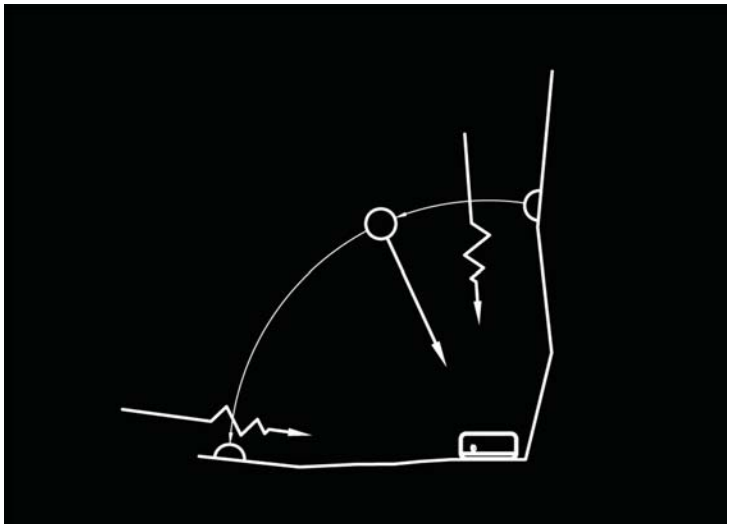


Figure 3.6 Site B exposure

3.5). Site B lies at the base of a hill but exposed on the other three sides (Figure 3.6). Site C is located inside an impact crater, protected on all sides from dust storms and solar/galactic radiation.

The next major criteria evaluated relates to the opportunity for expansion. Sites A (Figure 3.7)and B (Figure 3.8) provide ample room for growth, and a range of expansion options are available. Located within a crater, Site C (Figure 3.9) is rather constrained geometrically, and provides the most limited range of options for expansion of the three sites. With the flattest terrain of the three sites, Site A offers the greatest potential for expansion and flexibility.

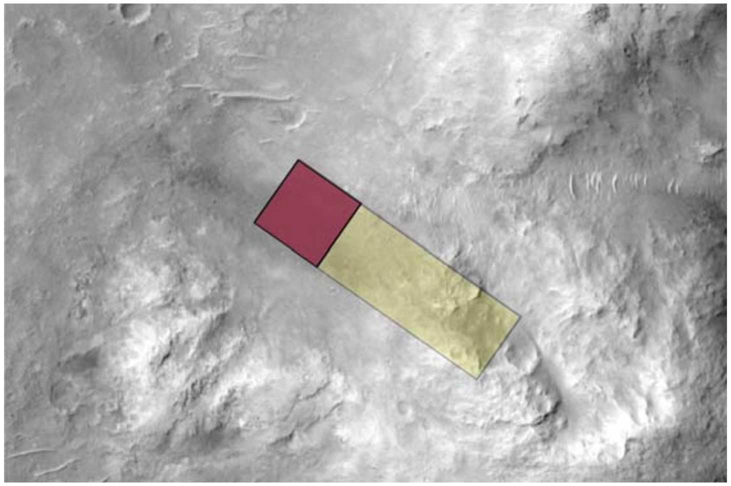


Figure 3.8 Site B expansion

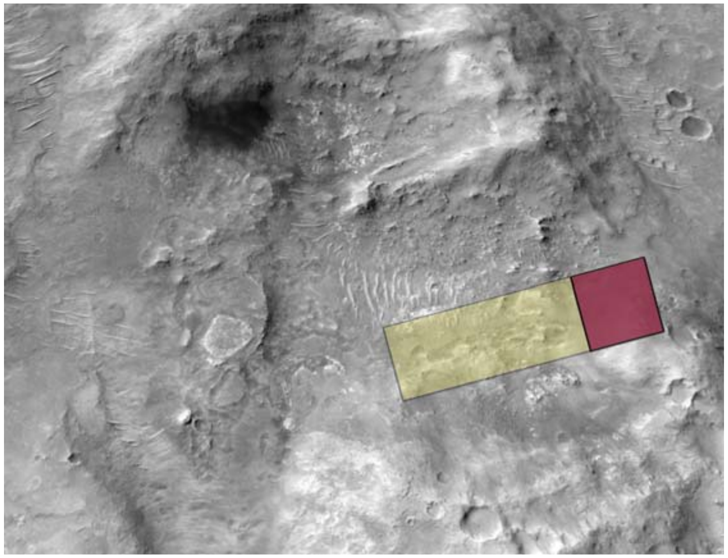


Figure 3.7 Site A expansion

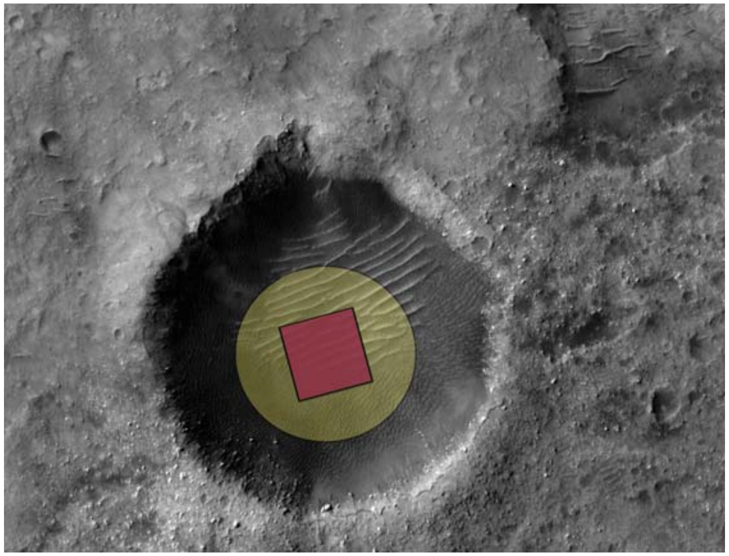


Figure 3.9 Site C expansion

The third and perhaps most important variable examined pertains to the opportunity for views to the surrounding landscape. Considering the development of materials and emerging technologies, it is highly probable that engineers will have solved the problem of radiation shielding, making opportunity for views the dominant factor in analysis for site location. The majority of this settlement is above ground, as views to the outside are decidedly critical to providing a sense of place, perception of space, and exposure to the natural environment. Views to the outside will help alleviate the negative effects of being contained within a sealed environment. The three sites provide ranging opportunities of view from maximum (Site A), to medium (Site B), and minimum to none (Site C). The crater walls that provide the protection from the elements also serve to prohibit any possible views to the broader surface beyond, overruling the potential for this as a site.

Site A was chosen based on the comparison of all available information. It offers considerable protection from radiation and dust storms being located between two hills, it has a relatively flat terrain with sufficient room for expansion, and offers sweeping views of the hills surrounding the site and to the plains to the east and west.

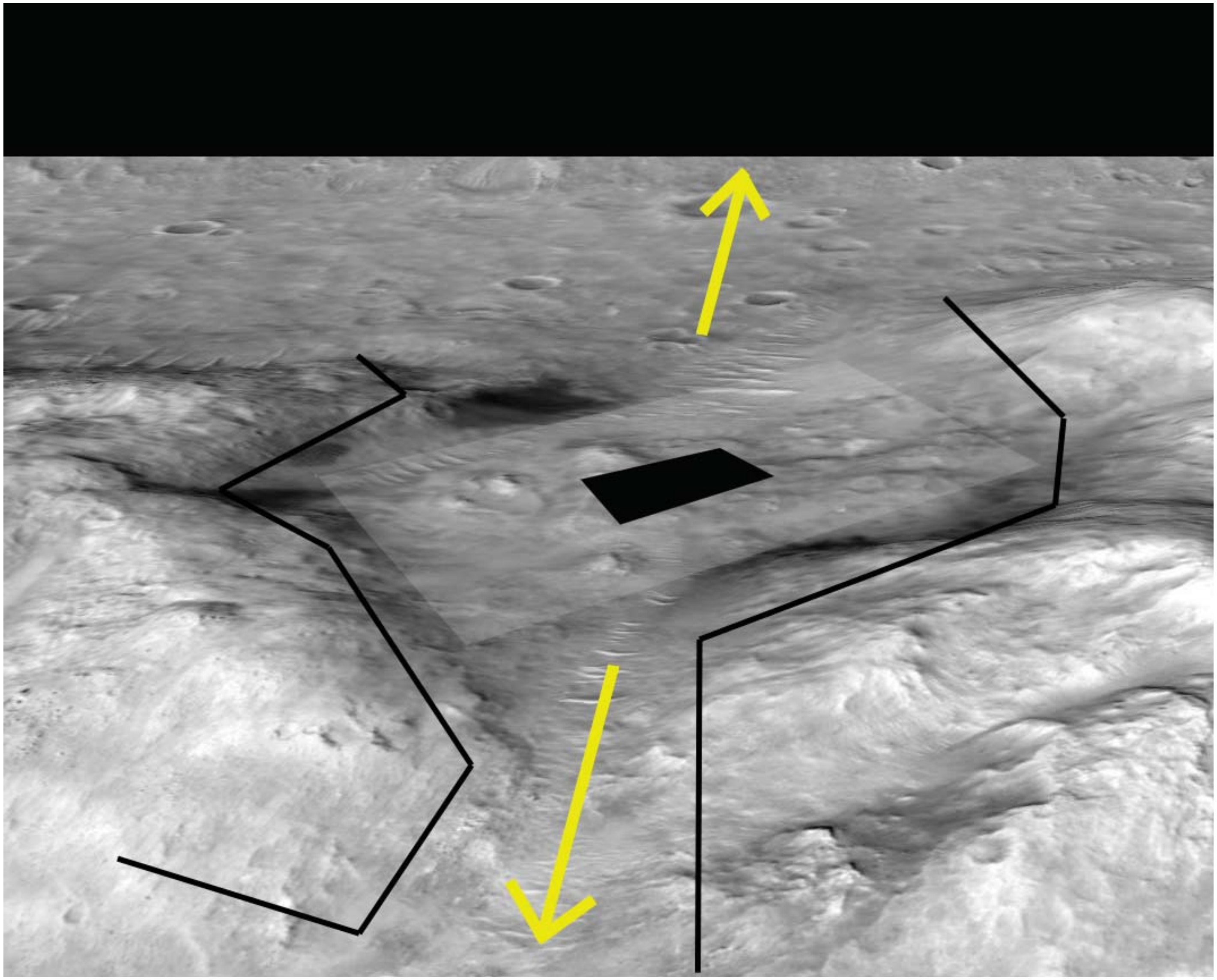


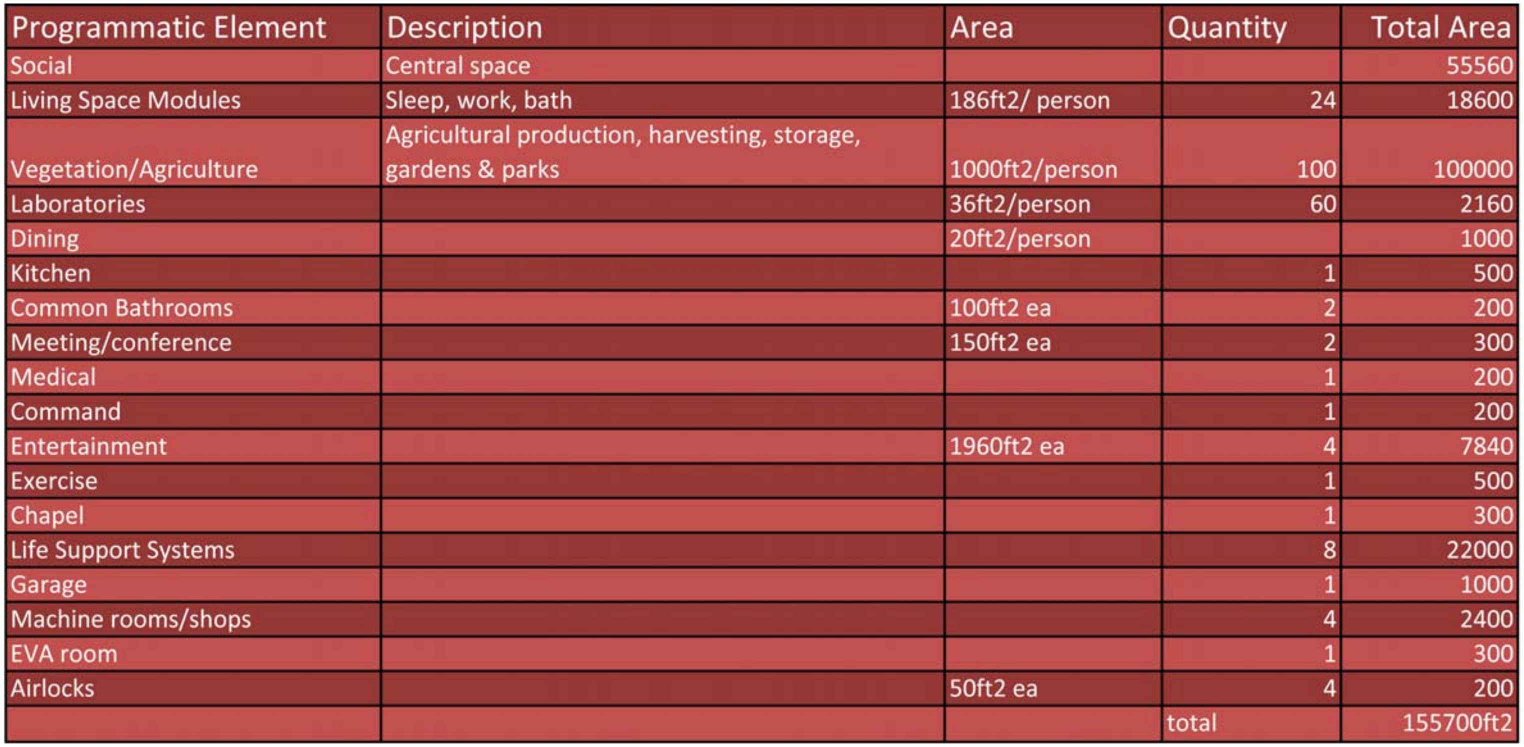
Figure 3.10 Site A conditions

4. PROGRAM

As described in the introduction, this project involves the design of a permanent Martian settlement to accommodate about 100 settlers in the year 2050. By this time, humans will have been operating continuously on the surface living in semi-permanent smaller-scale habitats, testing new technologies, conducting scientific research, and finally confirming the long-term viably living on Mars in permanent self-sustaining settlements. Ample resources such as water, oxygen, fuel (H^2), as well as metals and minerals for materials production will have been found, and the processes for extracting/mining these resources tested and proven. The first permanent settlements will probably be occupied mostly by scientists, engineers, and researchers, but the modular and programmable concepts of this design allow for flexibility of accommodations to suit any range of people. Eventually, all kinds of people will live on Mars, and there will be children and schools- everything that is here on Earth. This project does not go that far; the settlement as configured in the final design assumes the first hundred people will be adults, working on Mars to conduct research and facilitate broader settlement efforts on the planet.

Spatial planning of the settlement was based on a critical case study analysis, including the human factors element of design in extreme environments. Units in this project are all measured in English units (feet and inches) because of the intrinsic relationship linking architecture to people. Due to the programmable nature of this project, these numbers are flexible and subject to change based on the settler's needs. Future technological developments will most likely reduce many of the individual allotments. Certain conclusions were drawn where possible and emphasis placed, in particular on the living space modules. People are expected to spend as much as half of their time in these spaces, and space efficiency, comfort, and access to views are all critical to alleviate the negative effects of living in such an extreme environment.

As shown in Figure 4.1, the living space provided per person is 186 square feet, falling between the space provided by Petrov and the HAB modules described earlier. This was determined based on the design for a personal living space configured minimally for sleeping. Larger modules tend to have lower individual allotments due to shared spaces as shown in the final design. Emphasis was also placed on providing social space, and places for entertainment/recreation. Earlier projects often omit or under-provide these critical elements, whether due to economic reasons, or technical feasibility. The technology assumed to be developed in this thesis solves those challenges, presenting opportunities for much more livable conditions on Mars. Early in the design process it became apparent that there must be a central, large space for all the settlers



Programmatic Element	Description	Area	Quantity	Total Area
Social	Central space			55560
Living Space Modules	Sleep, work, bath	186ft2/ person	24	18600
Vegetation/Agriculture	Agricultural production, harvesting, storage, gardens & parks	1000ft2/person	100	100000
Laboratories		36ft2/person	60	2160
Dining		20ft2/person		1000
Kitchen			1	500
Common Bathrooms		100ft2 ea	2	200
Meeting/conference		150ft2 ea	2	300
Medical			1	200
Command			1	200
Entertainment		1960ft2 ea	4	7840
Exercise			1	500
Chapel			1	300
Life Support Systems			8	22000
Garage			1	1000
Machine rooms/shops			4	2400
EVA room			1	300
Airlocks		50ft2 ea	4	200
			total	155700ft2

Figure 4.1 Space program

to share and use. This idea of a central park, or square began with the first town-planning on Earth, and it is appropriate for the first towns on Mars as well. It was decided that the settlers will also need smaller public spaces for entertainment and recreation, where they can gather in smaller subgroups.

The Biosphere 2 project (Figure 4.2) showed that 2000 square feet of agricultural space per person is enough to nutritionally sustain one person in the largest closed system ever created. Advanced hydroponic systems, genetic engineering and other technologies will certainly reduce this number over the next 40 years, and the space provided per person in this project is 1000 square feet. Despite this projection, the greenhouses still account for almost one-half of the entire settlement, as shown in Figure 4.3.

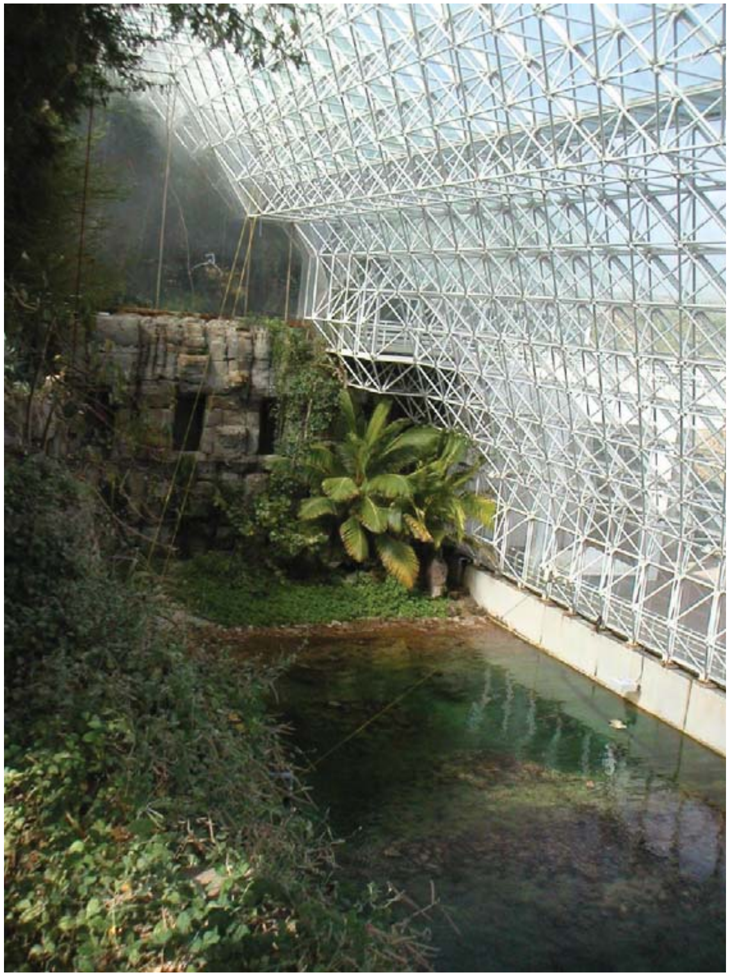


Figure 4.2 Biosphere 2

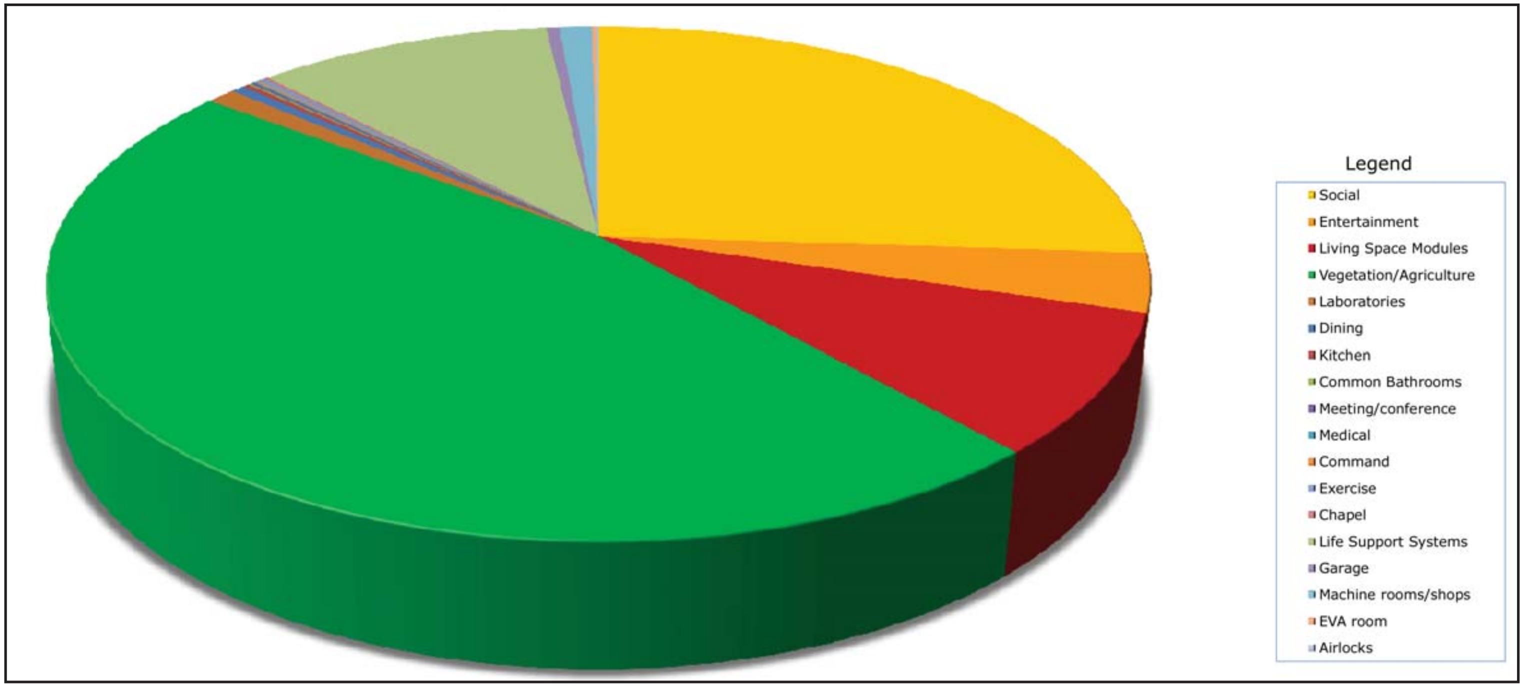


Figure 4.3 Space Distribution

5. CONCEPTUAL DESIGN

Ideas developed through case study analysis and research into emerging technologies greatly affected the conceptual design of the settlement. All prior studies utilize existing methods and technology to define the architecture of the first human habitats on Mars. With a target date of 2050 for this project, many assumptions can be made as to the development of new building techniques and engineering possibilities that will be employed in this permanent settlement. Future technologies will enable the design and construction of structures on Mars impossible to imagine when constrained by present technological limitations. Rather than approach present technical challenges as an obstacle, this thesis approaches these challenges as an opportunity for exploration of new possibilities and technologies.

5.1 Concept

The most obvious current obstacle to transporting the settlement from Earth is gravity, and the cost of launch associated per unit of mass. Rockets also have a certain payload (mass) maximum, which cannot be exceeded per rocket design. The next major design challenge involves dimensional limitations assuming the rocketry rules as defined in NASA's Mars Reference Mission. As can be seen in Figure 5.1, there are dimensional limitations of approximately 16' x 16' x 40' within the bay of a rocket that can be landed softly on the Martian surface.

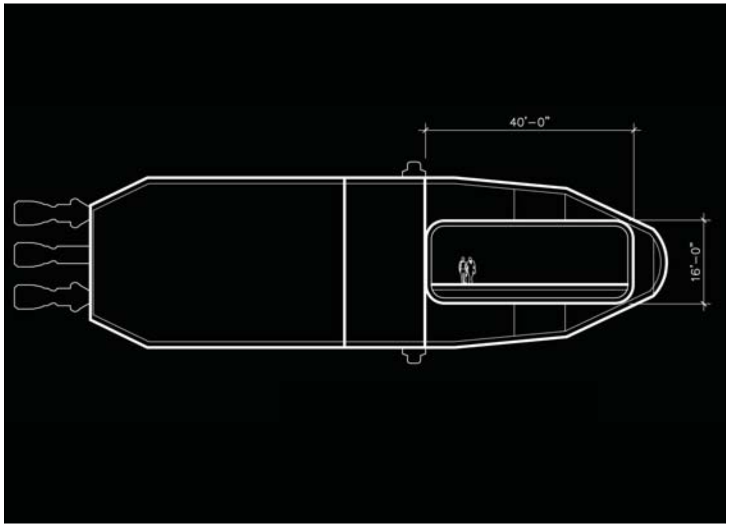


Figure 5.1 Transport limitations

Another major challenge presenting today's designers for the Martian environment involves radiation shielding. Current theory suggests one foot of water is required to be sufficient insulation to protect against the worst effects of major solar events. Considering the technologies being developed today, it is logical to assume that material sciences will produce much greater insulators, and this number will be greatly reduced. It is even conceivable that radiation shielding will not even be a design factor in 40 years, as "Researchers working at the Science and Technology Facilities Council's Ruthersford Appleton Laboratory, the Universities of York, Strathclyde and IST Lisbon, have undertaken experiments to show it is possible for astronauts to shield their spacecrafts with a portable magnetosphere-scattering the highly-charged, ionized particles of the solar wind and flares away from their space craft (www.physorg.com)." If science can produce a portable force field to shield future spacecraft (Figure 5.2) from solar radiation, there seems to be no reason this idea could not be applied to a fixed settlement on the surface of Mars. Present-day limitations severely hinder the ability to design comfortable living spaces and larger social spaces for people on Mars without using inflatable or expandable structures. The use of future technology, including programmable matter and nanotechnology will enable designers to free themselves from the constraints of gravity and size, and current materials.

Figure 5.2 Force fields

The construction of this settlement involves a minimal human crew (5-6) people already on the surface of Mars, living in semi-permanent HABs, conducting scientific research and experiments. In the year 2048, a series of rockets launched from Earth in 2047 land softly near the Husband Hill site, carrying with them the "seeds" for the first permanent programmable Martian settlement. These "seeds" contain the basic programming information and minimal initiation materials/ nanobots for the triggering of the construction process. The term "seeds" is analogous to the concept of how a tree grows from a seed (Figure 5.3). With a seed, an incredible amount of information is programmed into the smallest organic unit, and the growth of a large and complex tree occurs automatically given proper environmental conditions, an energy source and nutrients necessary for growth. This settlement will grow much in the same way, and humans will play a more supervisory role instead of being the actual "builders."

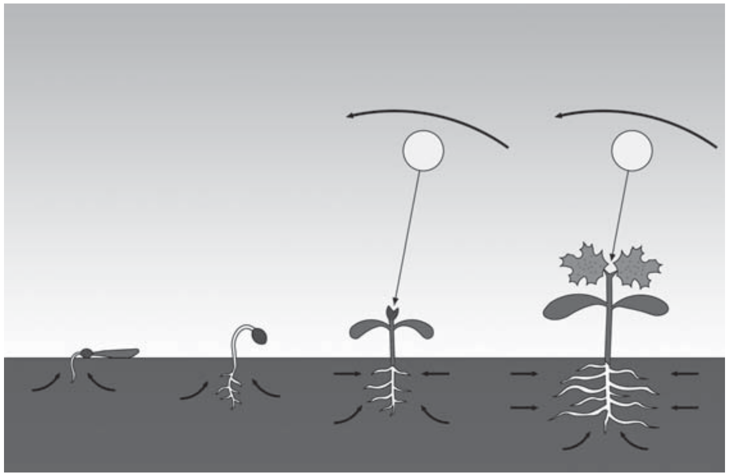


Figure 5.3 Seeds

Nanotechnology will enable micro-machines programmed to do everything, including mining raw resources for building materials, chemical and material factories and processors, constructors, and most importantly, replicators. The process starts off apparently slow, and at a scale invisible to humans, but constantly increases with an exponential rate of growth. As one replicator replicates itself into two replicators, those two replicate to produce four, there is a constant doubling in the speed and growth of the settlement. The people are there mainly to set up the process, initiate the construction, ensure the program is being executed according to plan, and to make changes/modifications as necessary. It is projected that the entire construction of the settlement will take two years, and the 100 settlers arrive to a fully-constructed, operational settlement in the year 2050. This ability to create machines that make other machines, and modular robots that combine to form larger robots capable of more difficult tasks will change the way work is done. With the major technical issues addressed, design can now be approached from a more architectural perspective, and permanent space designed based primarily on human needs rather than current physical limitations.

5.2 The scale of the city

The approach taken during the conceptual design phase of the settlement focused on two distinct architectural scales, that of the city, or settlement, and the scale of a human being. The third scale typical of most architectural projects, that of the detail, was omitted due to the sheer complexities involved when dealing with things that have yet to be invented.

A project of this scale is much like planning an entire town or city, and requires a clear organization, logical circulation, and a hierarchy of space. Earth-based layouts were considered and analyzed for value in masterplanning the settlement. The first plan examined was the "Linear City," a linear configuration credited first to Arturo Soria in his partial plan for Madrid, which is still evident today (Figure 5.4) and also studied by LeCorbusier. The plan has its benefits, a logical compact linear design and is easily expanded along the main axis. It also has its problems, particularly with respect to traffic and congestion, and travel distances from extremities to central points.

After initial sketches were made it was decided that a radial plan (Figure 5.5) was more appropriate for this settlement. A radial plan provides a natural center, and focal point for people to gather. The need for a hierarchy of space, and a large central social space in settlements on Mars is a main objective of the design, and considered to be one of the most crucial elements that must be provided for permanent settlers on Mars. A radial plan also

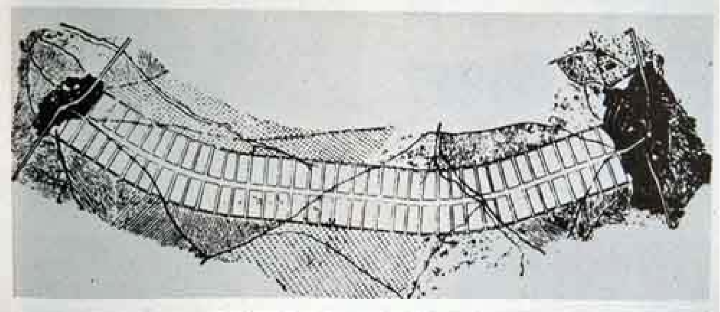


Figure 5.4 Linear city, Arturo Soria & Mata

Figure 5.5 Radial city

reduces the maximum travel distances to central points, and it provides a greater flexibility of program distribution. The flexibility can accomodate varying programmatic demands. Initial concept sketches shown in Figures 5.6-5.8 investigated potential masterplanning options.

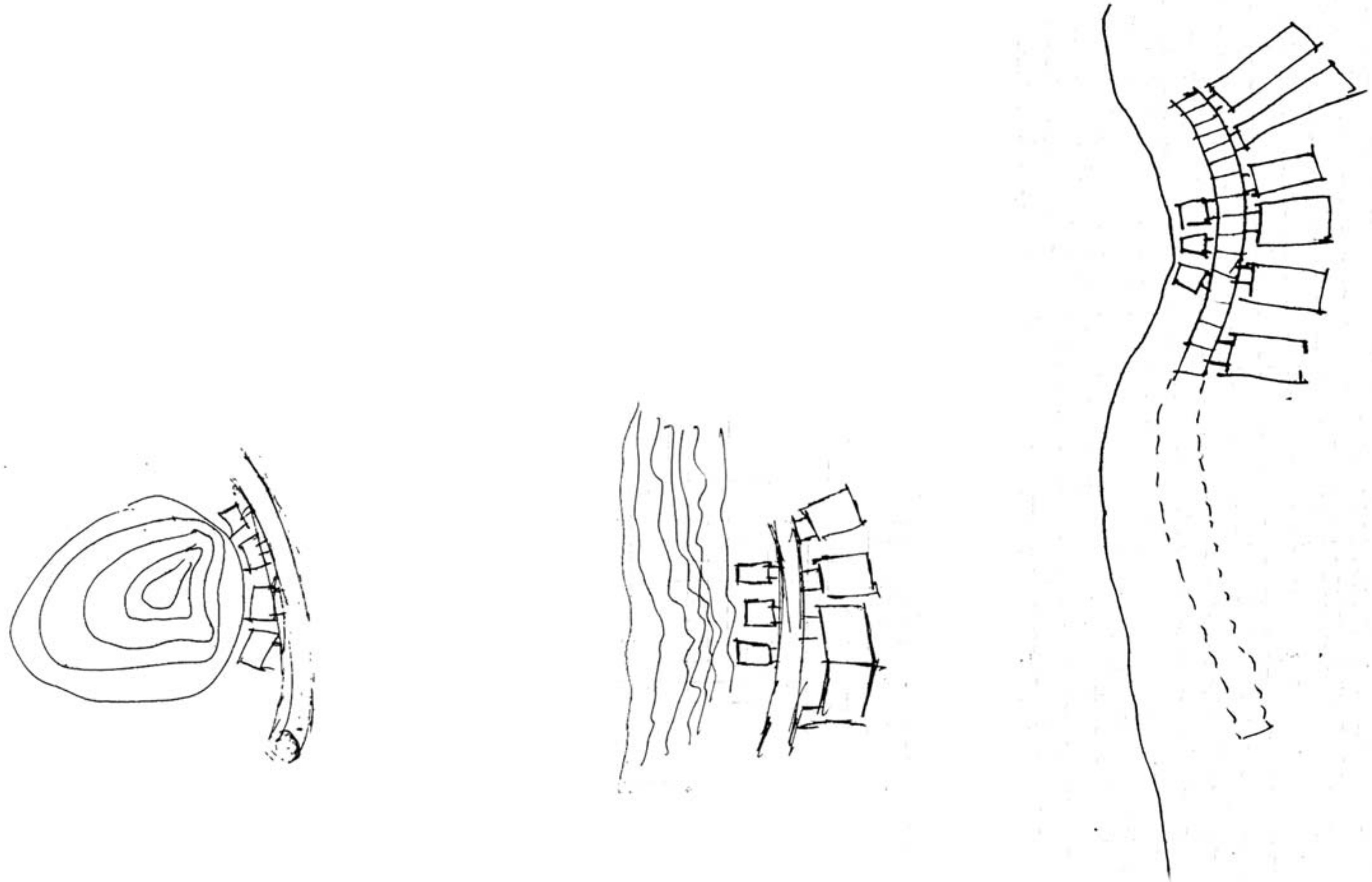


Figure 5.6 Concept sketches- linear city

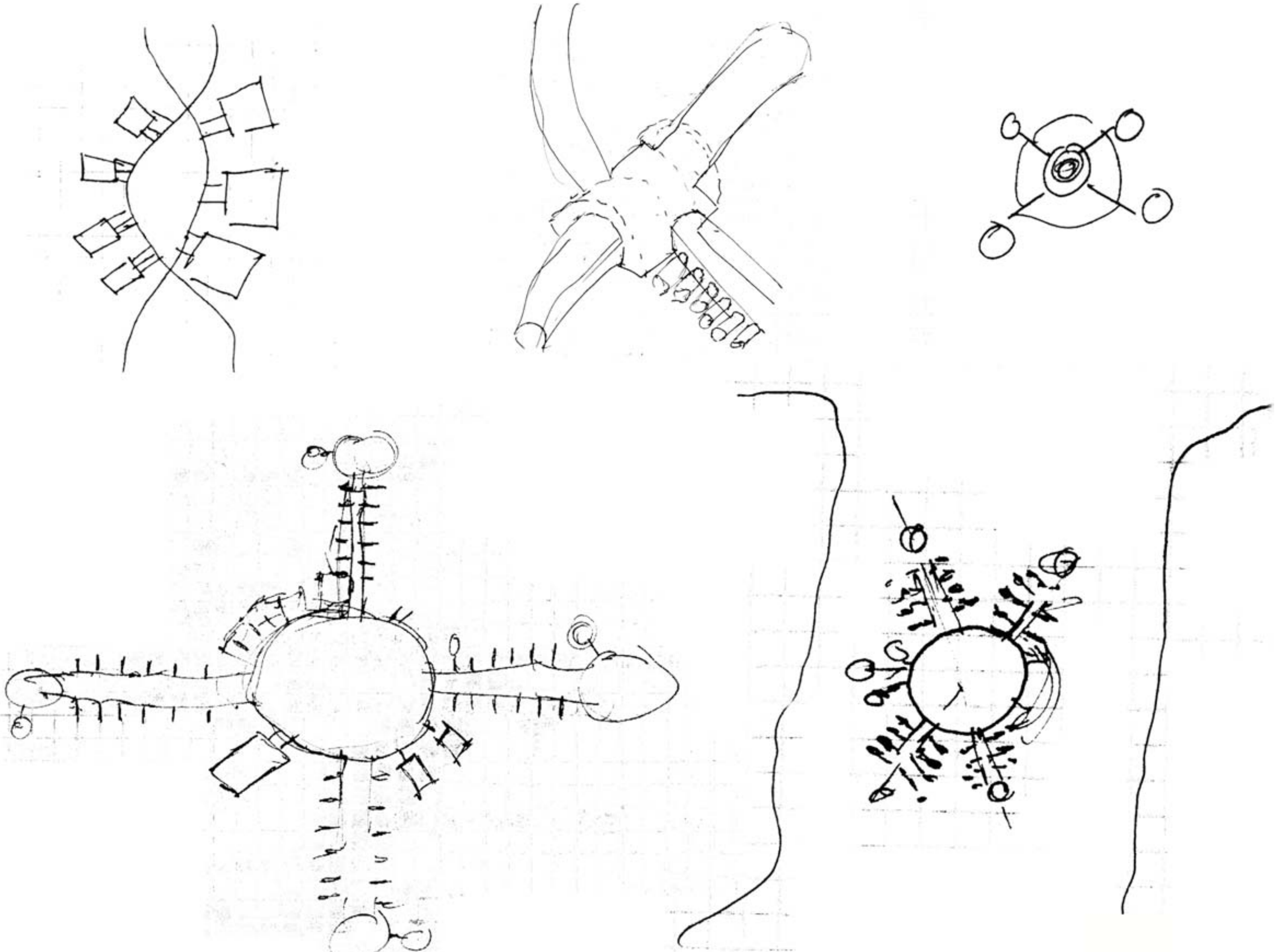


Figure 5.7 Concept sketches- radial city

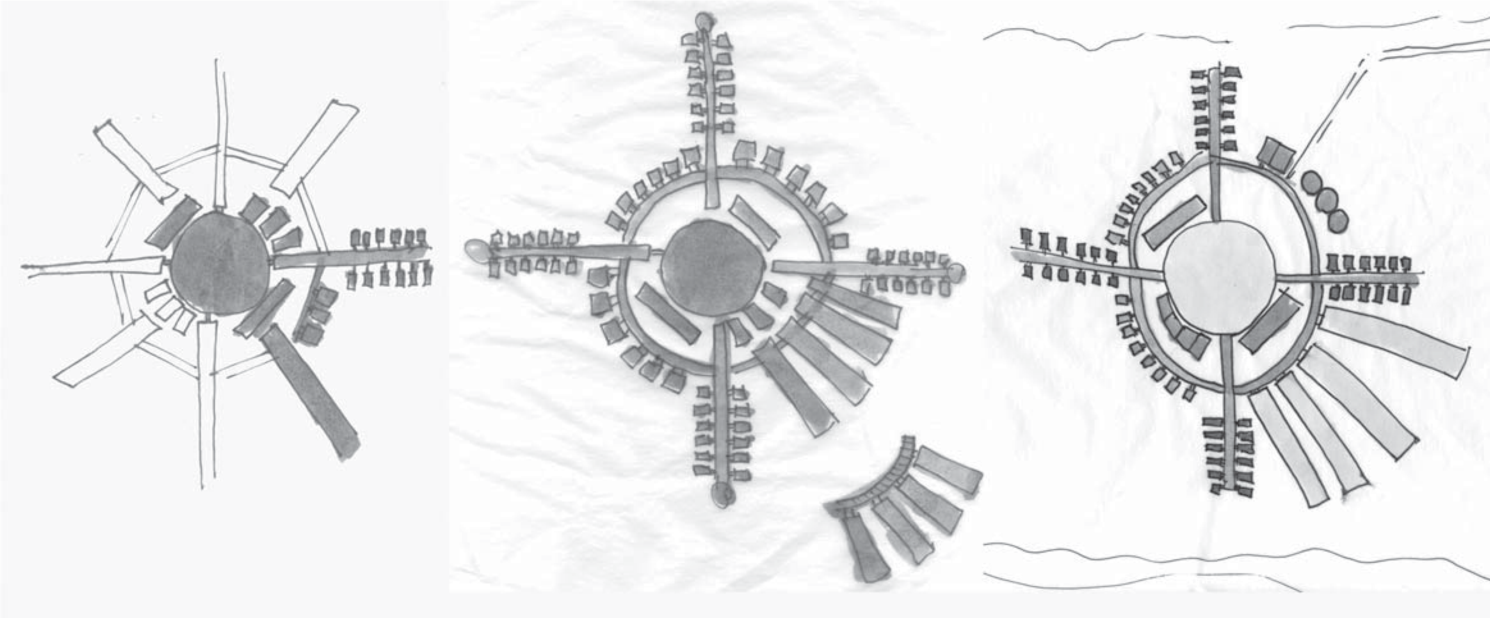


Figure 5.8 Schematic planning

5.3 The scale of the human

The second scale examined relates to the scale of a human being, how individual people occupy and use space around them. Case study analysis and human factors indicate a greater need for personal private space and common social space than previous, semi-permanent or short-term settlements. After determining the basic program shown in Section 3, each of the programmatic spaces was evaluated in terms of its use or function, and occupational needs. The following list describes a series of spatial “modules” that was generated based on the requirements of each space:

•Living space modules- private living quarters, expected to be occupied for extended periods of time, and design for comfort is critical. Places for sleep, work, and entertainment.

•Circulation modules- corridor-like spaces connecting all of the infrastructure and life support systems throughout the settlement. Need to accommodate both pedestrian and light vehicular traffic. Transitional spaces occupied for short amounts of time, and can be inflatable structures.

•Greenhouse modules- provide all of the nutritional needs of the settlers. Hydroponic gardens stack vertically to reduce the architectural footprint on the landscape. Minimally occupied by people, the greenhouses can also be inflatable.

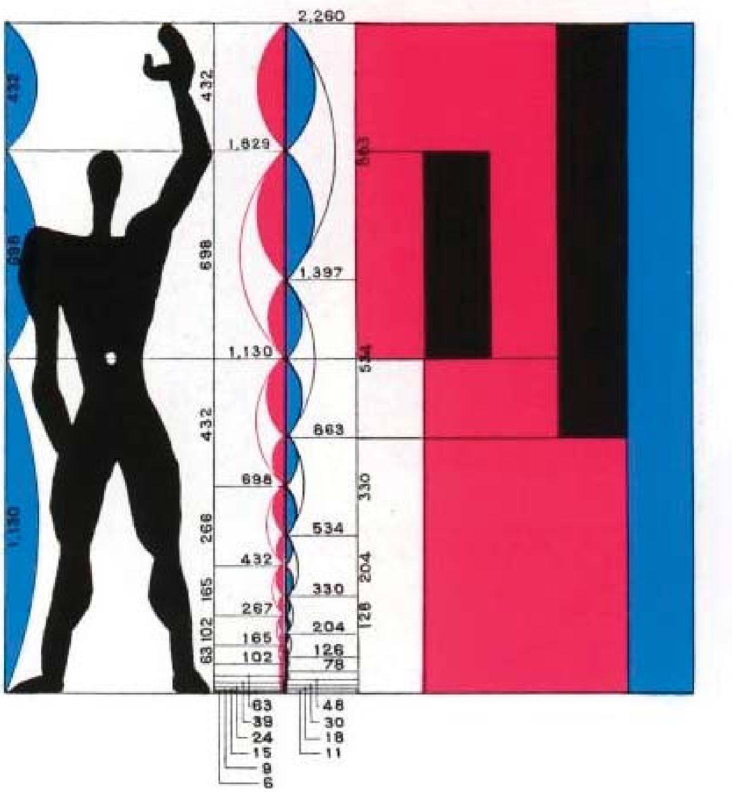


Figure 5.9 *Modular Man,* Le Corbusier

•Entertainment modules- larger scale, social spaces where people will meet, socialize, and relax. Qualities of both indoors and outdoors, and flexibility of space is necessary.

•Work modules- similar in needs to the living space modules, these structures are programmed to accommodate laboratories, machine shops, and other work-related functions. Occupied by multiple people for extended periods of time, comfort and views out are important.

•Industrial modules- large rigid structures which contain all of the life support systems, food processing plants and storage, power generators and battery storage banks, etc. Not occupied by people under normal conditions, views to the outside are not critical.

With the most critical modular components defined programmatically, the next step was to design the modules as architectural spaces and define structural systems. Spaces that are not usually occupied, or only occupied temporarily were decided to be inflatable structures. These are easier and cheaper to construct, and due to minimal expected occupancy by people, should have little or no adverse affect on people. They are also ideal forms and structures considering the forces exerted on the building skin once pressurized for human occupation. The psychological effects of long-term human occupation of inflatable structures are largely unknown, and the comfort potential of such extended occupational appears to be minimal at best. Therefore the living space modules and work modules were designed as “rigid” structures.

Figures 5.10-5.15 show the conceptual design process of the spatial modules.

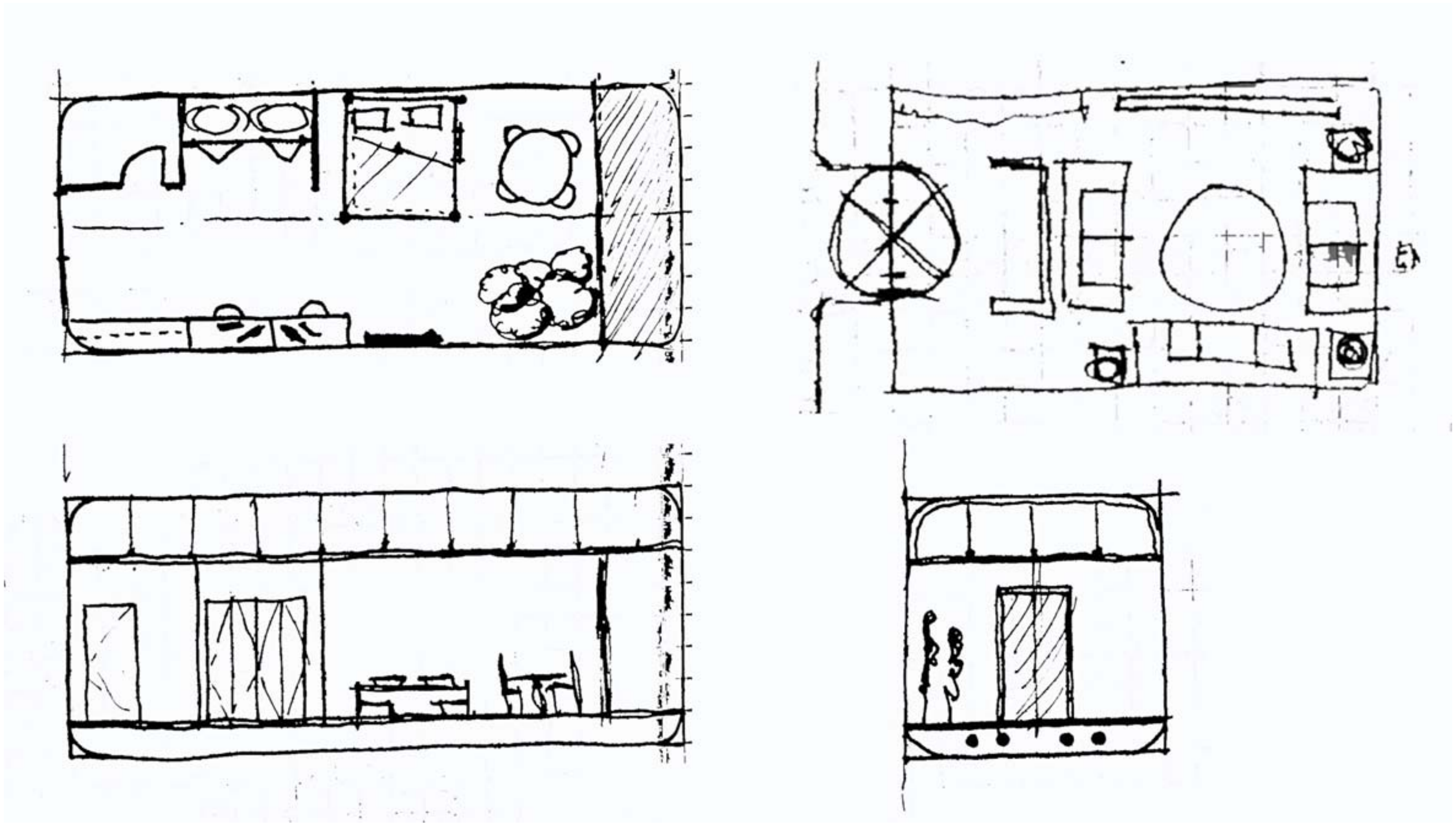
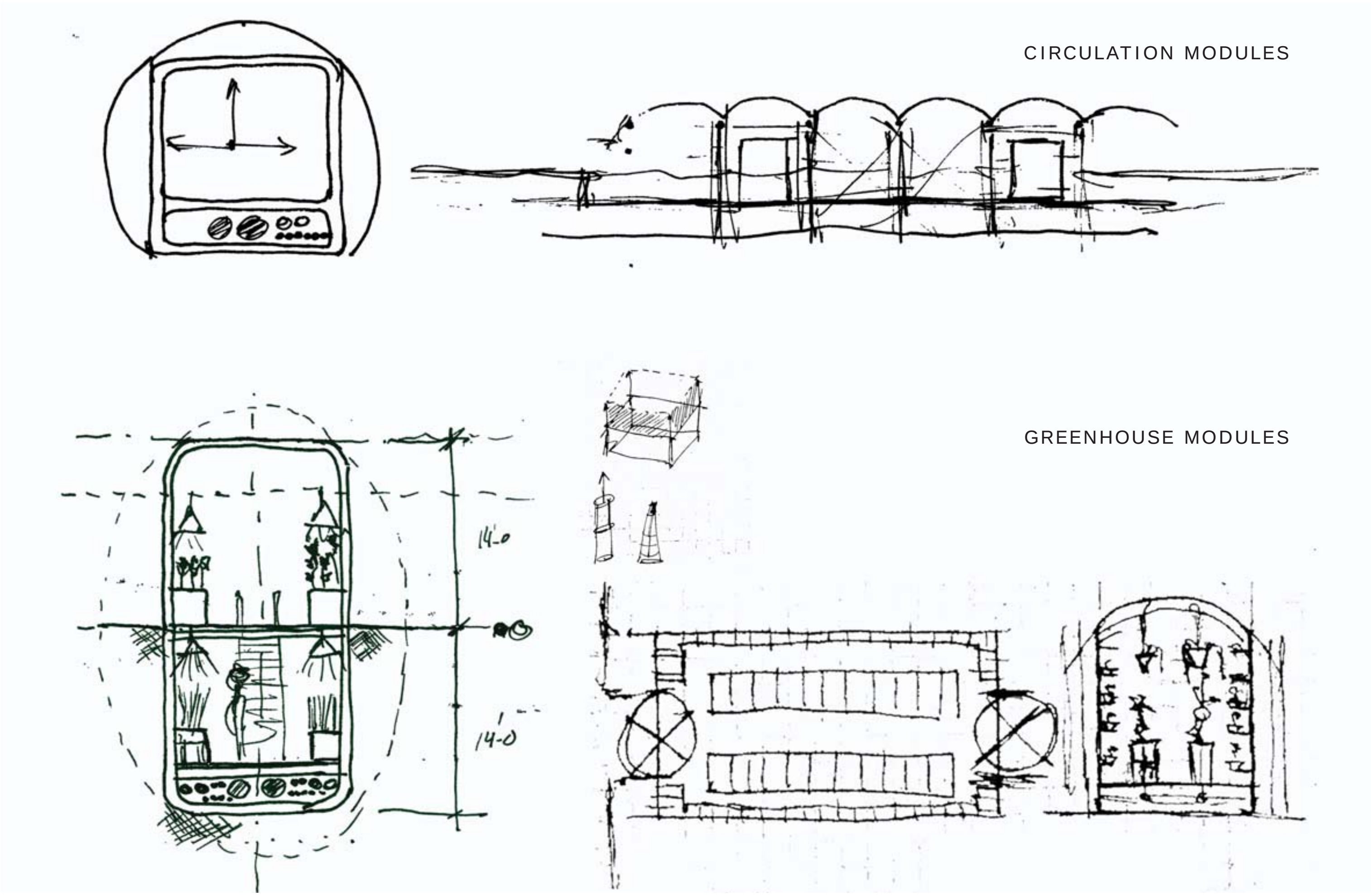


Figure 5.10 Concept sketches- living spaces



CIRCULATION MODULES

GREENHOUSE MODULES

Figure 5.11 Concept sketches- inflatables

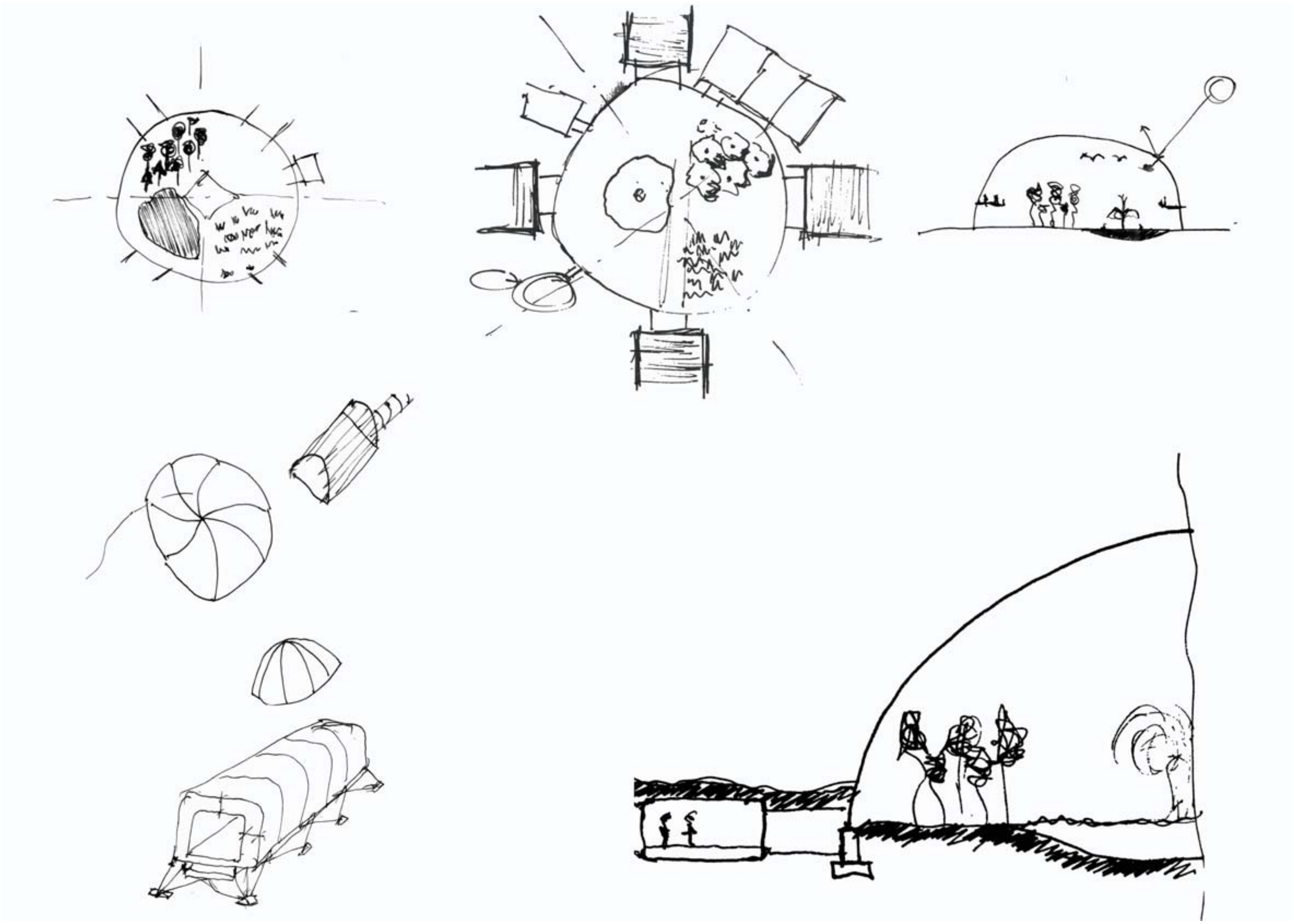


Figure 5.12 Concept sketches- social spaces

The final phase of conceptual design involved combining the ideas developed from studying the program at two separate scales into a single schematic masterplan, and generating three-dimensional forms of the individual modules.

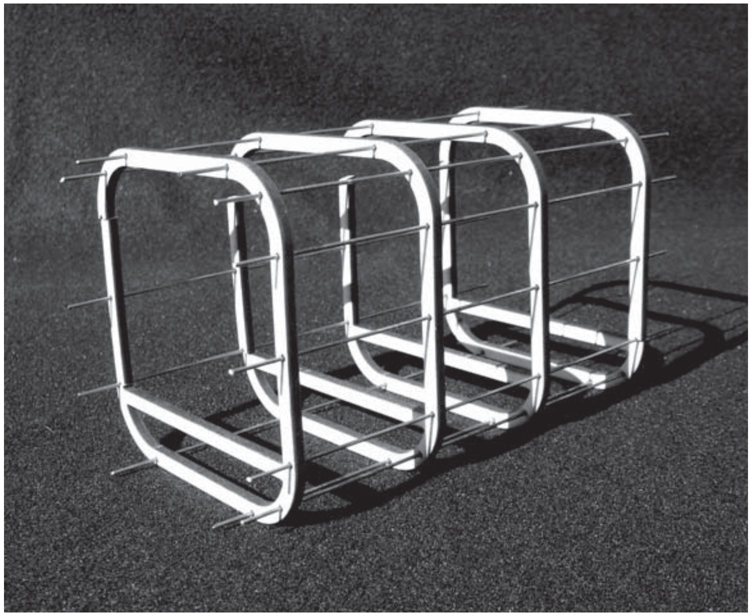


Figure 5.13 Inflatable concept models

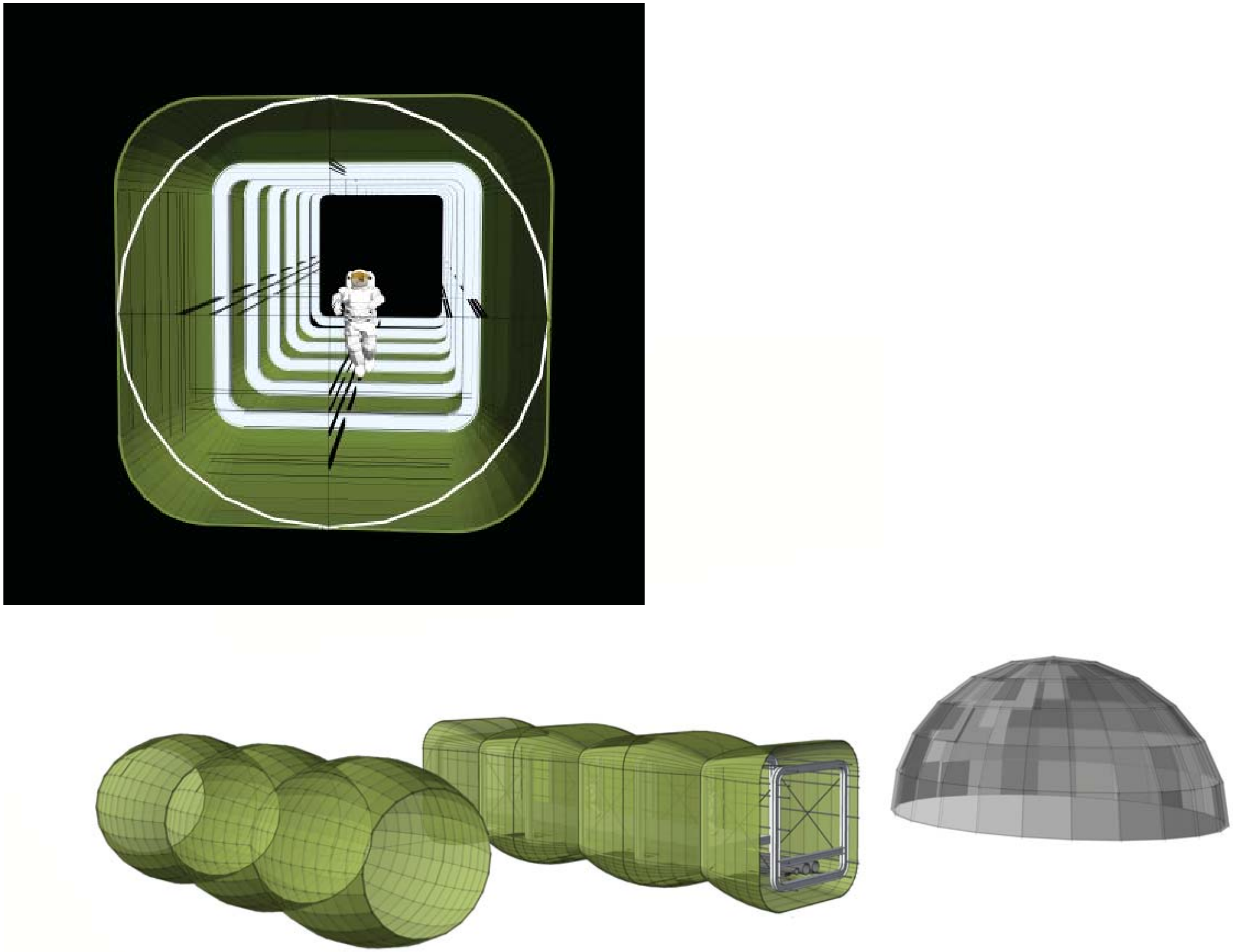


Figure 5.14 Conceptual modules

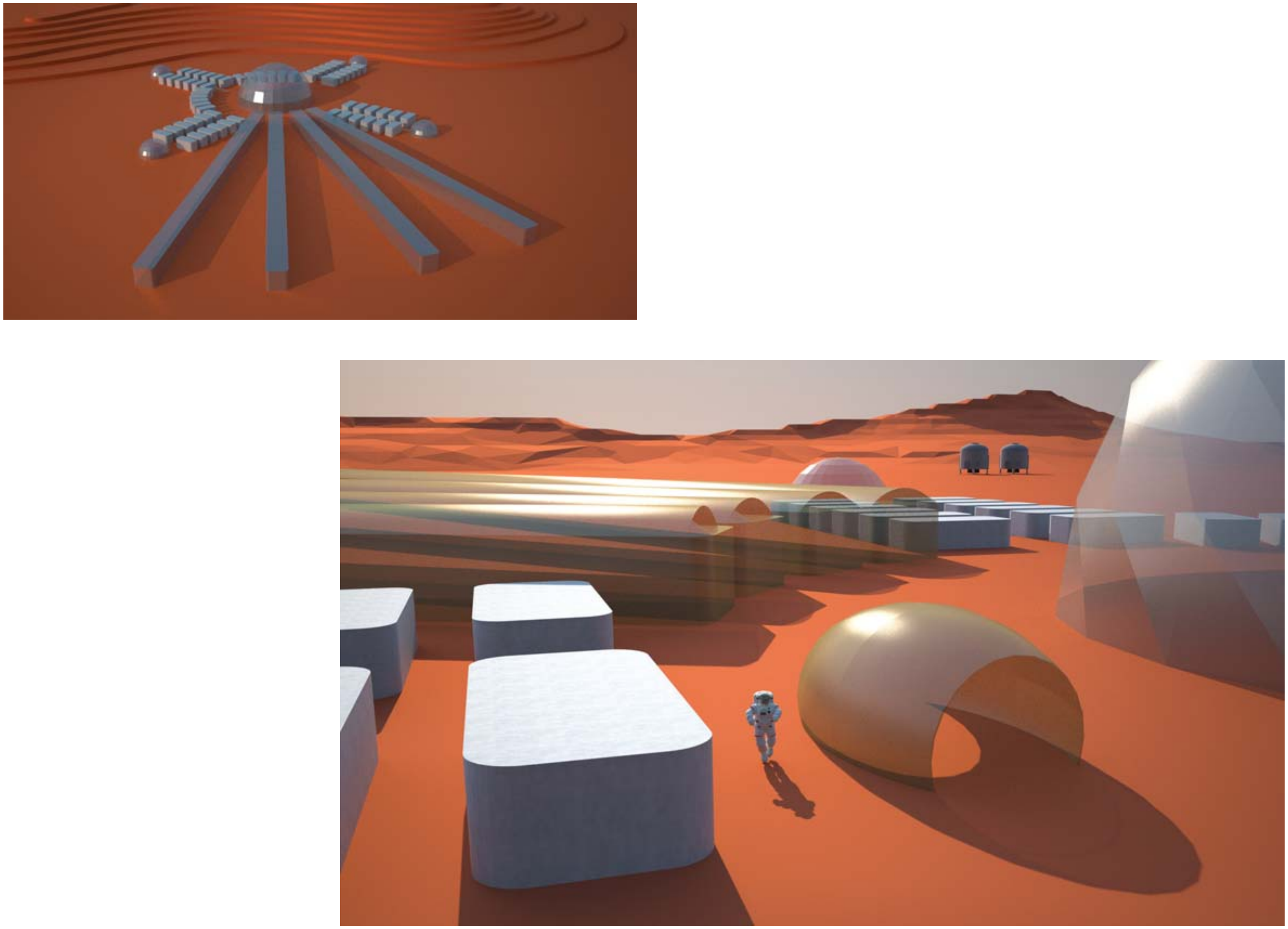


Figure 5.15 Schematic planning

6. Final Design

The final design presented utilizes the technology and ideas developed in Section 5, and assumes that science has solved most of the major technical challenges facing today's designers for permanent settlements on Mars by the year 2050. Emphasis was placed on providing a balance of public, and private space, and minimizing the effects of the extreme environment. The following sections describe the design of the settlement, first at the scale of the settlement or master plan, then at the scale of the modules, and finally the sustainable strategies that are employed in this settlement.

6.1 Settlement plan

The overall plan of the settlement focuses on the large central park in the middle of the settlement. As shown in Figures 6.1-6.6, a perimeter ring of circulation modules wraps the base of a large inflatable dome covering the central park, connecting "wings" of programmatic elements radiating from a central point. Four residential wings of living space modules are terminated by smaller social spaces or "entertainment modules," where various subgroups of people can gather and socialize. These were located in the north and west quadrants of the project to maximize protection from the hill to the north of the settlement. Laboratories and greenhouses were located in wings in the southern half of the settlement, to maximize solar exposure to the greenhouses. The life support system wing was placed as far away as possible from the living space modules because of the small nuclear reactor provided as a redundant power system.

The central park is divided into three main spaces. In the southern space, a large water feature recycles water through aquatic plants for the greenhouses and greywater systems. In the northwestern space, trees and other plants provide a shaded area, and a grassy field covers much of the northeaster portion of the park. By providing a large space with conditions identifiable on Earth, it is intended that these spaces will provide the psychological relief and social opportunity to mitigate many of the side effects associated with Martian colonization. The domes require minimal structure and the barrier between inside and outside to provide the desired effect, and are explored in greater detail in Section 6.5.

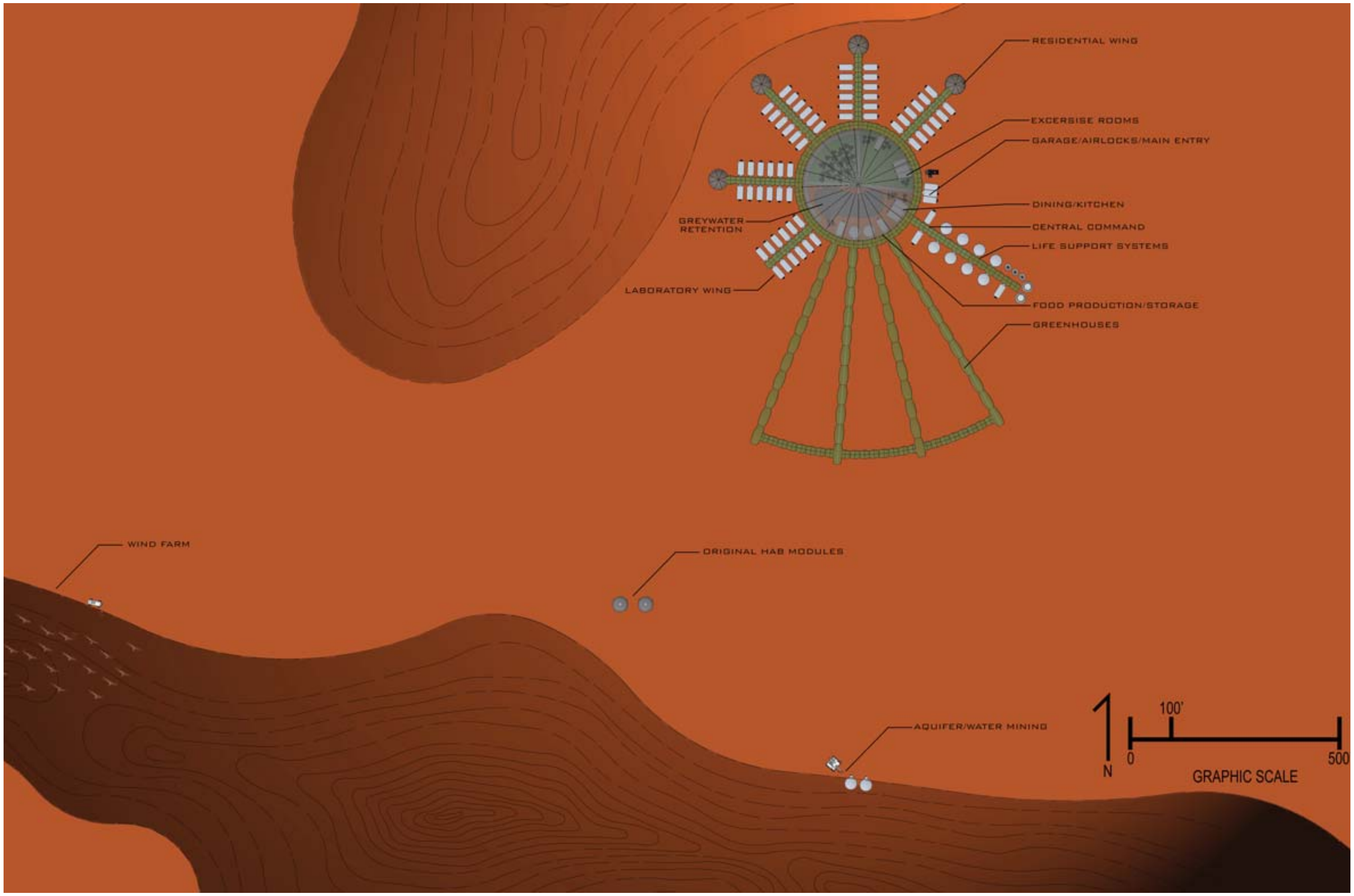


Figure 6.1 Site plan

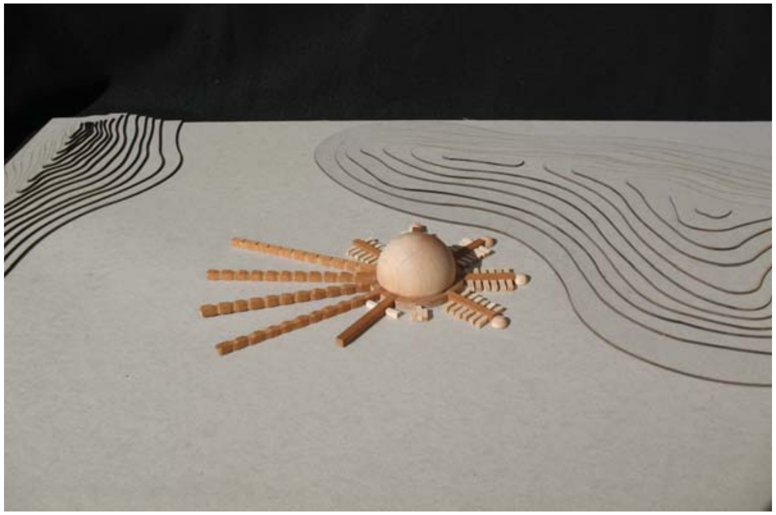


Figure 6.2 Site model

Figure 6.3 Site model

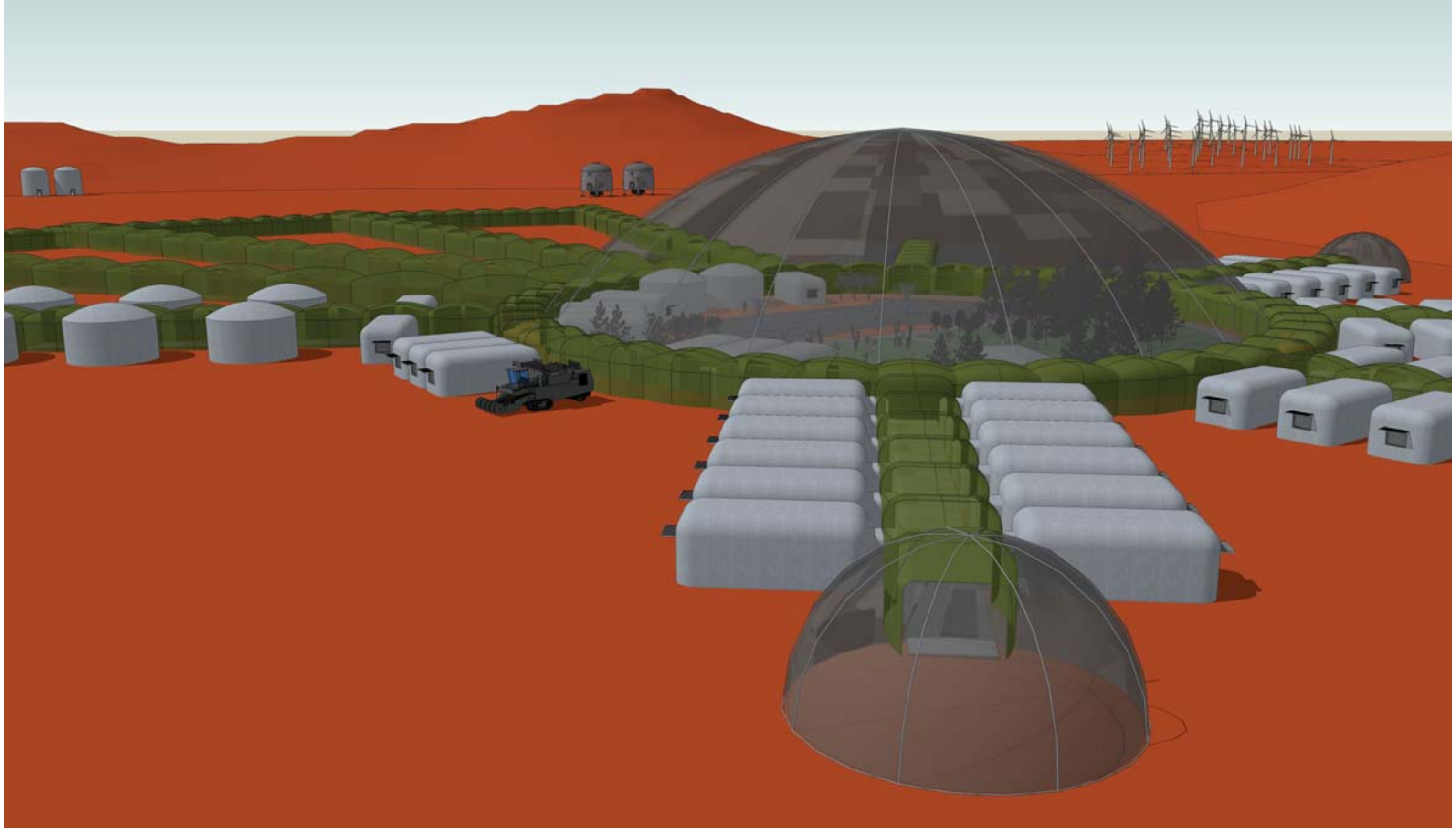


Figure 6.4 Aerial perspective from northeast

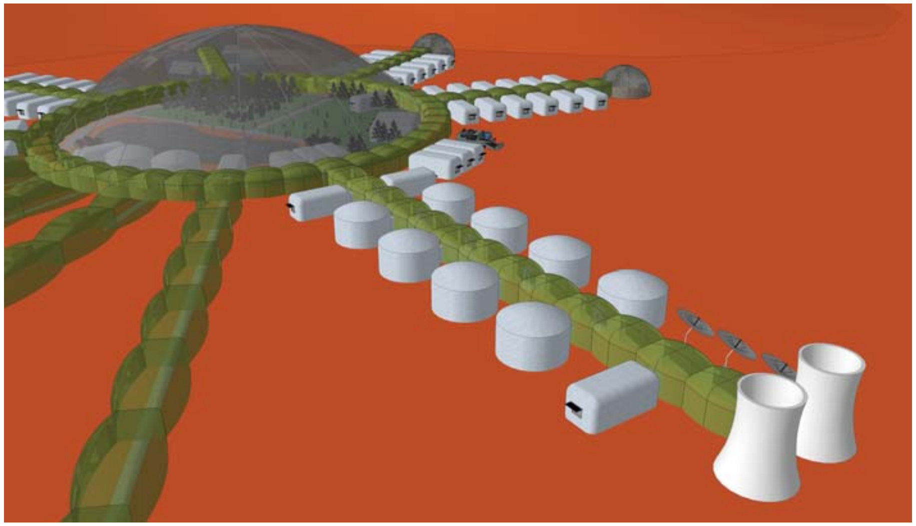


Figure 6.5 Life support wing

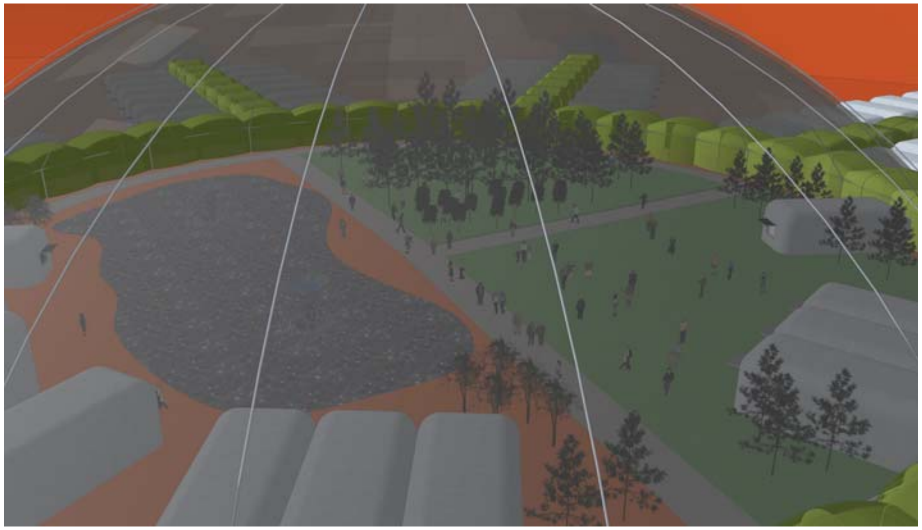


Figure 6.6 Enlarged Center

A modular approach to the design of the settlement was taken for several reasons described earlier. Most importantly, a modular architectural scheme provides a system of control in assuring consistent design in terms of comfort and quality of space, while allowing a flexibility of configuration to suit a range of site conditions and programmatic demands. Four modules were identified as critical to the success of the settlement, due to their expected use and function, where architectural design can play a greater role. The living space modules, circulation modules, greenhouse modules, and entertainment modules (Figure 6.7) were studied in greater detail as shown in the following sections.

Figure 6.7 Critical modules

6.2 Living space modules

The living space modules are the private living quarters for the settlers, and are expected to be occupied for extended periods of time. Living spaces must provide places for sleep, work, and entertainment. Three different living space modules provide for a range of people living together in single-person units, doubles, and “quad” units. Opportunity for views to the surrounding landscape is of critical importance, and backup life support systems are built into the modules in case of emergencies. Airlocks serve as the entry and provide a safe means of egress. These modules are rigid structurally, yet made entirely of programmable matter. The user can customize the spatial configuration of the modules via a digital interface with the module’s artificial intelligence system.

Figures 6.8-6.12 show a potential single or two-person unit. Figures 6.13-6.26 show how the living space module can be programmed to accommodate other needs and arrangements.

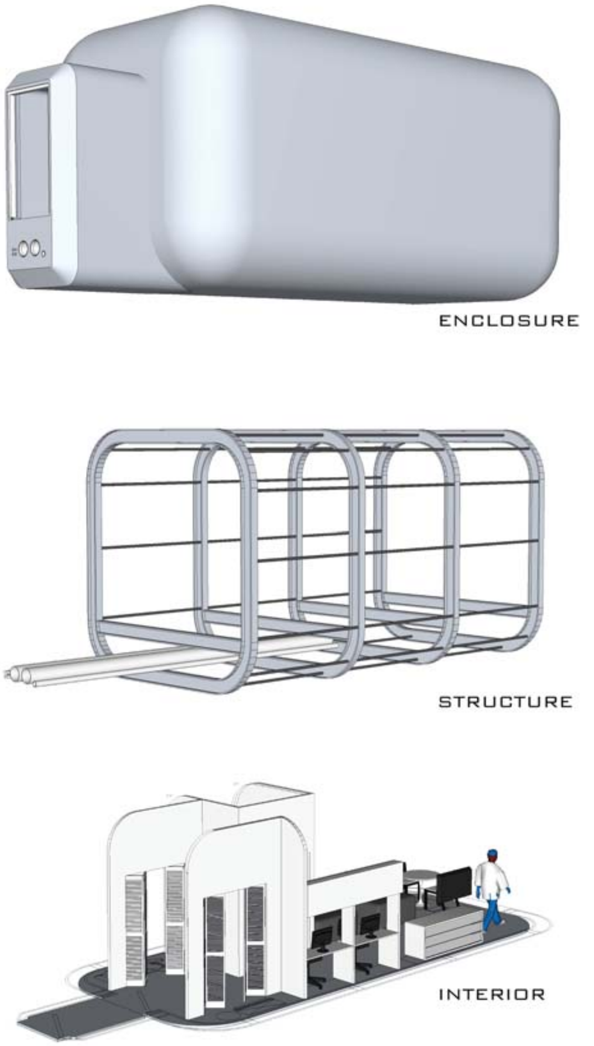


Figure 6.8 Exploded axonometric

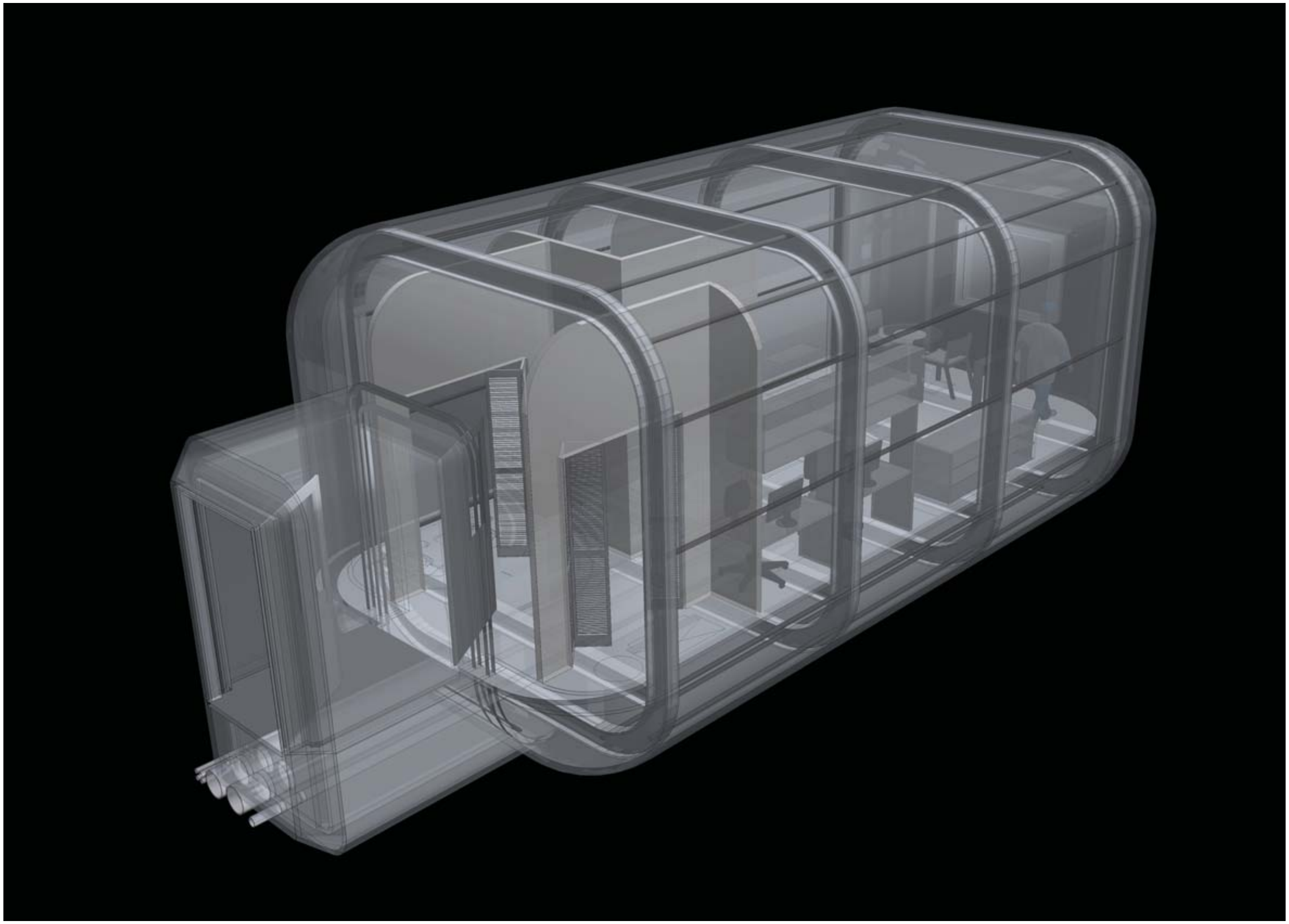


Figure 6.9 Living space module

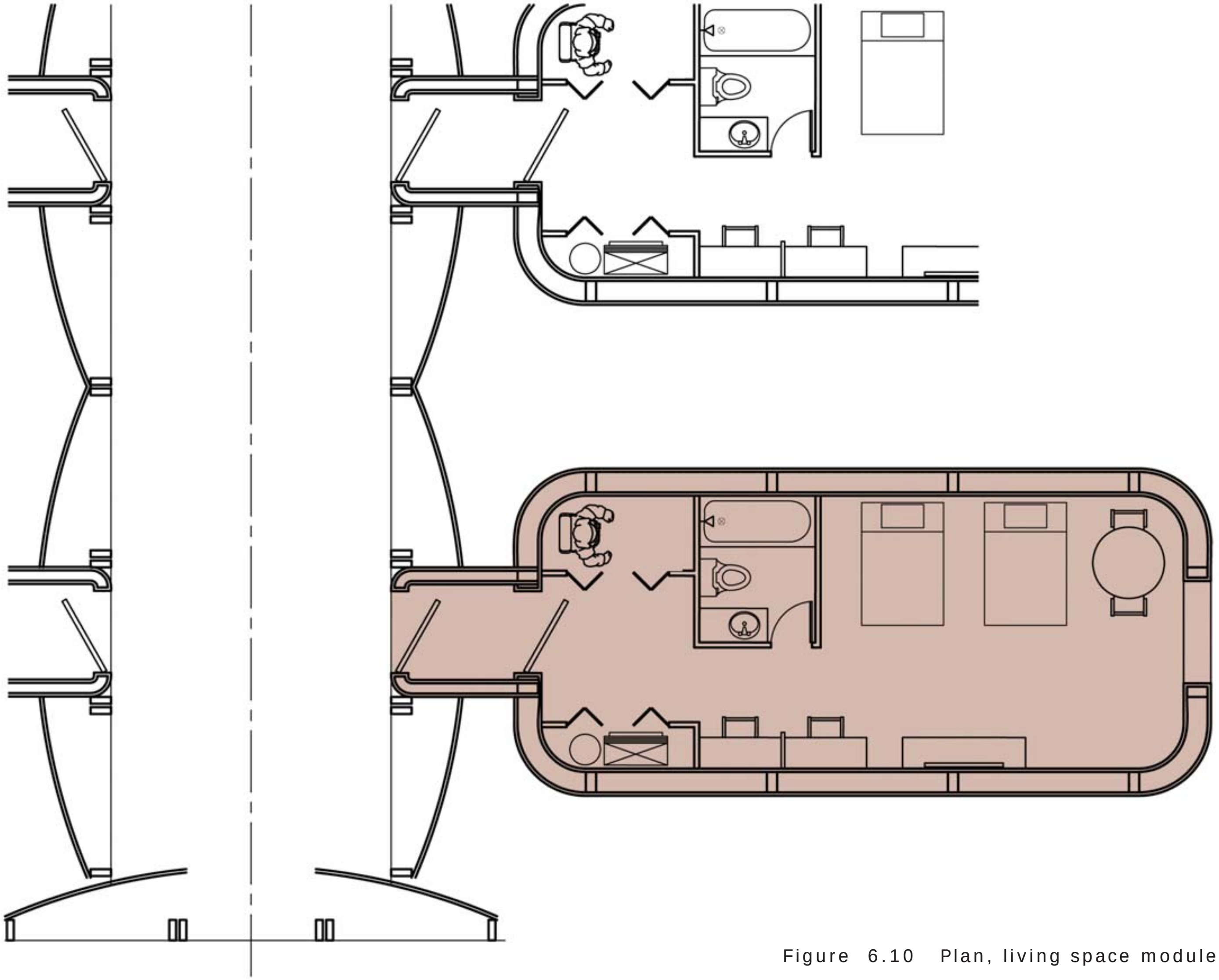


Figure 6.10 Plan, living space module

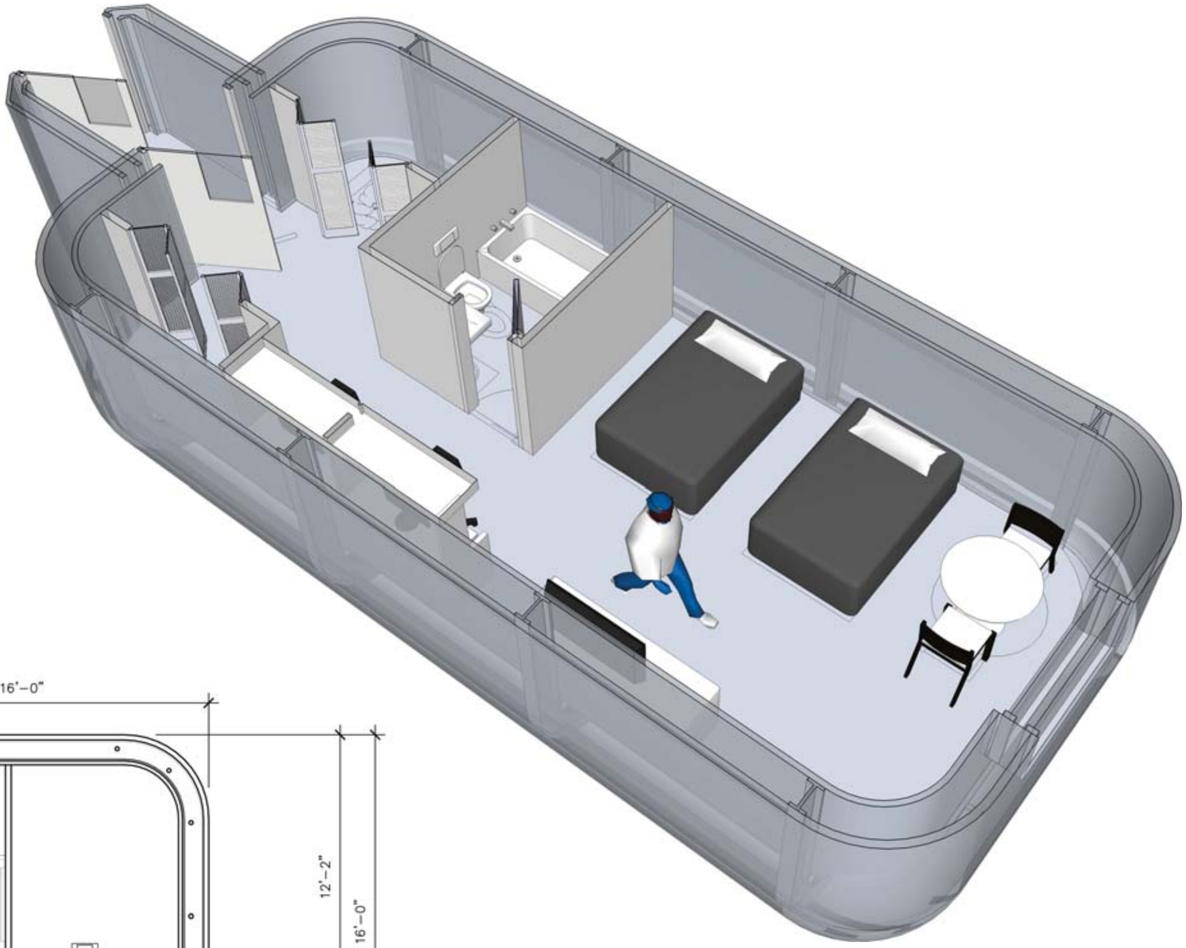


Figure 6.12 Plan perspective

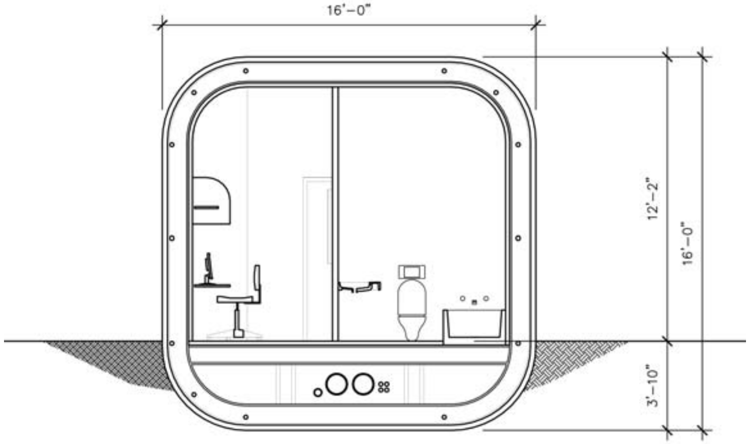


Figure 6.11 Section, living space module

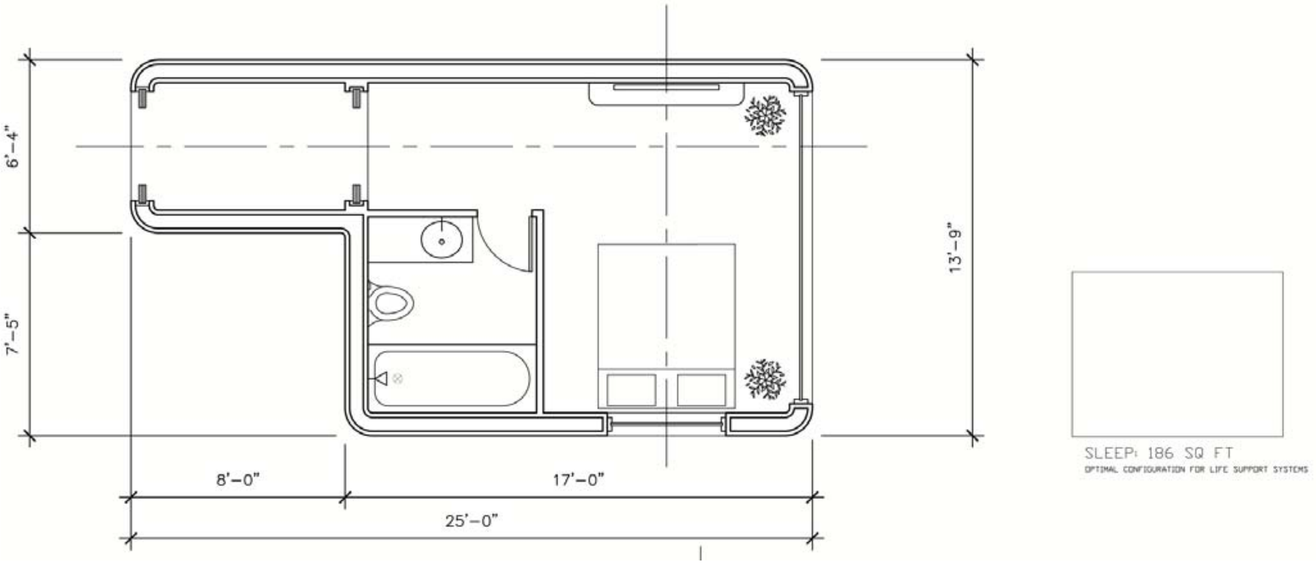


Figure 6.13 Plan, single- sleep

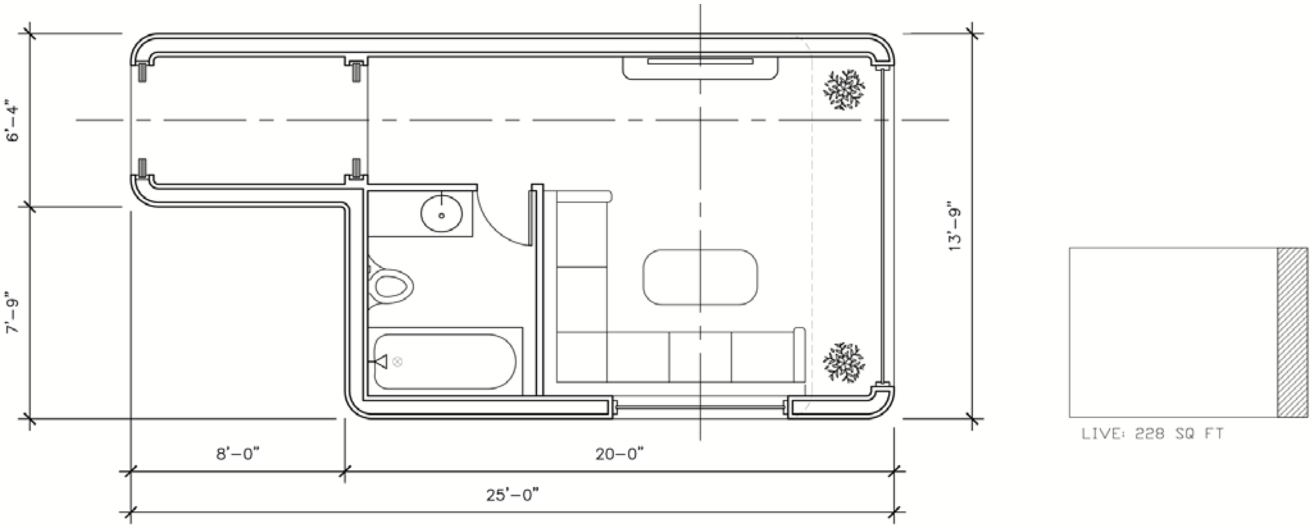


Figure 6.14 Plan, single- live

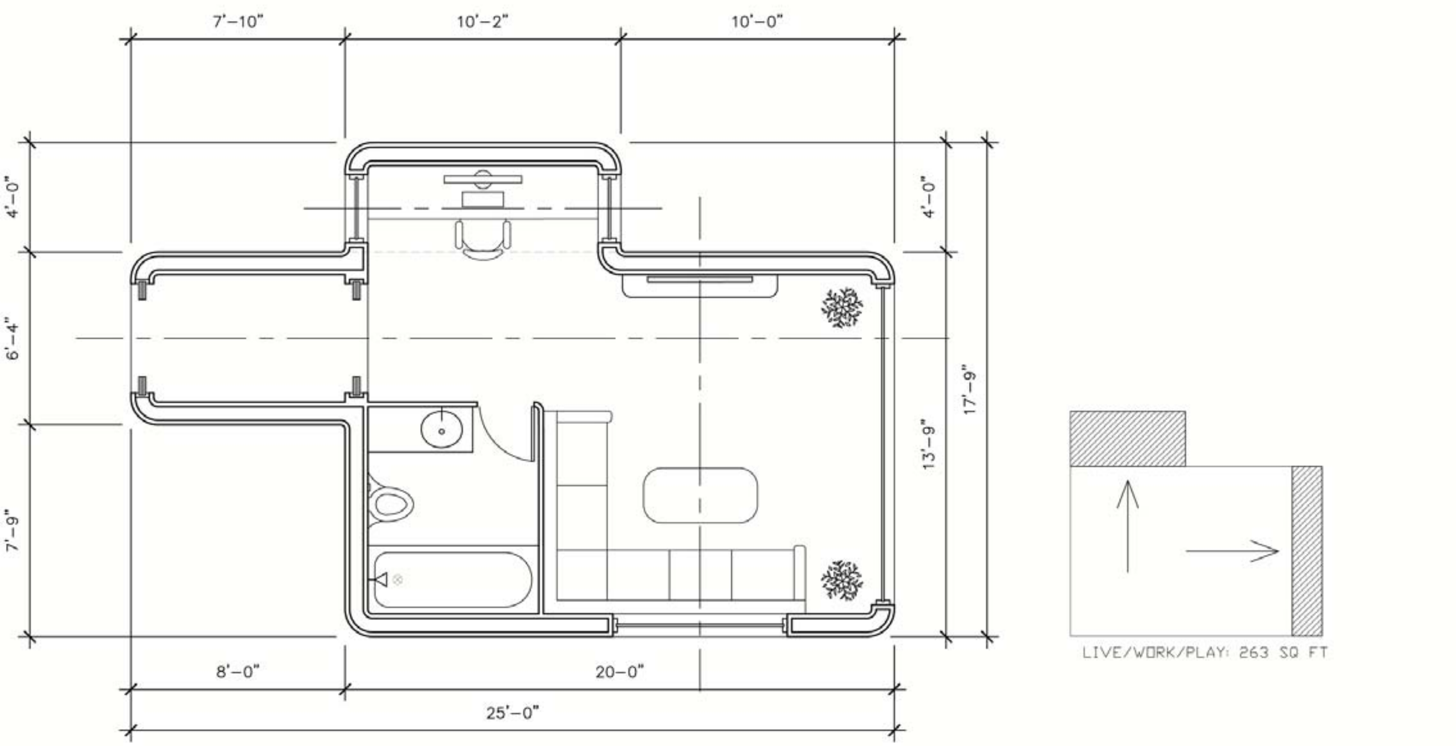


Figure 6.15 Plan, single- live + work

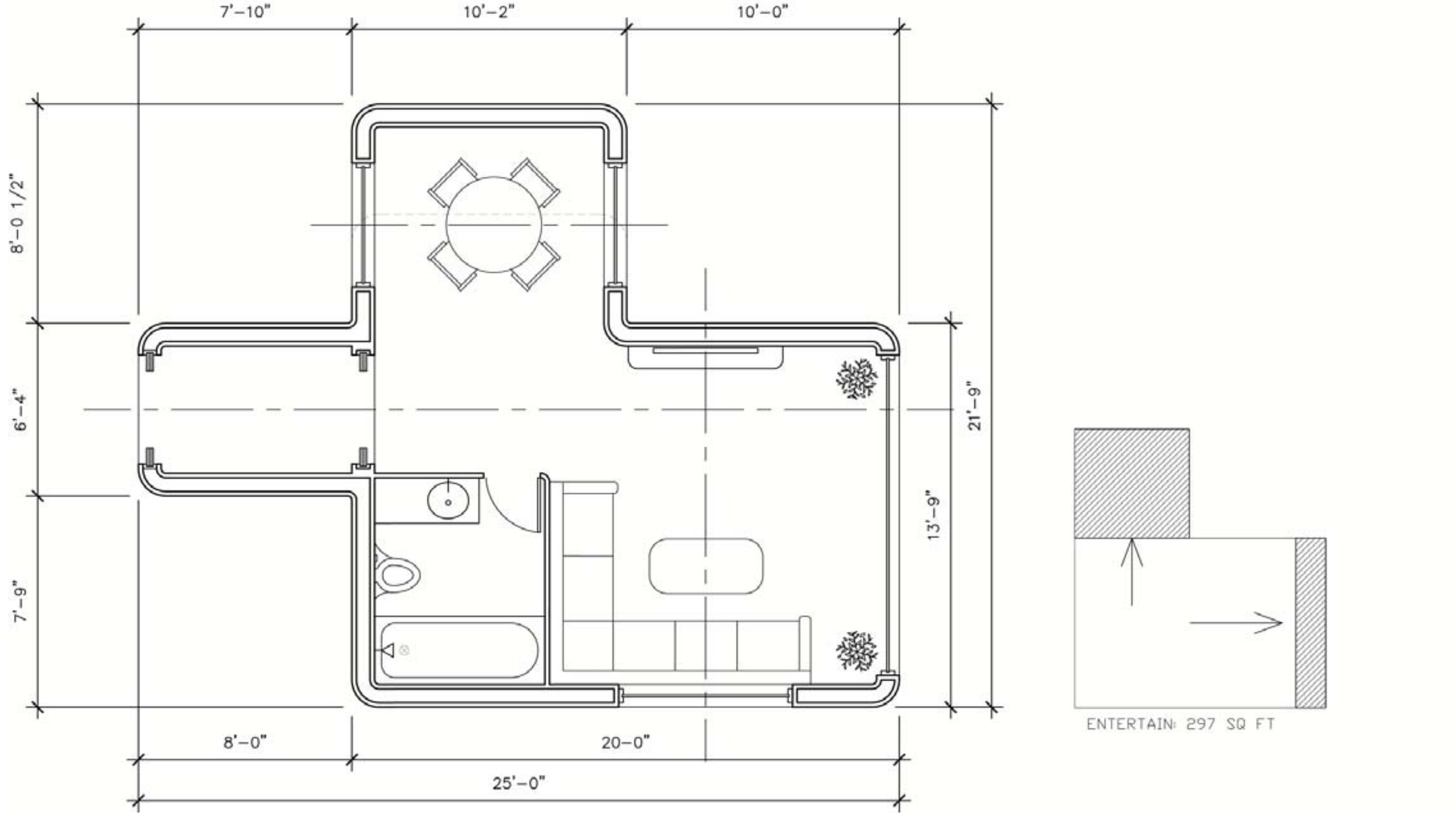


Figure 6.16 Plan, single- entertain

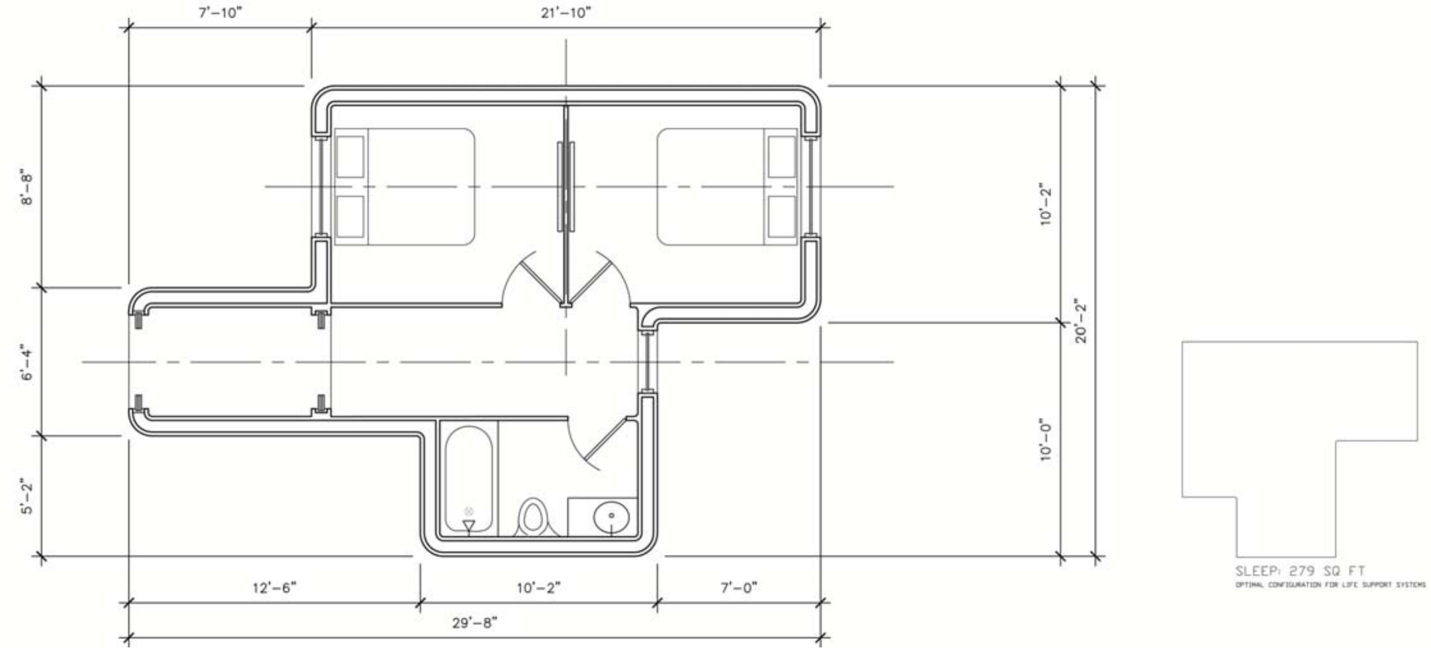


Figure 6.17 Plan, double- sleep

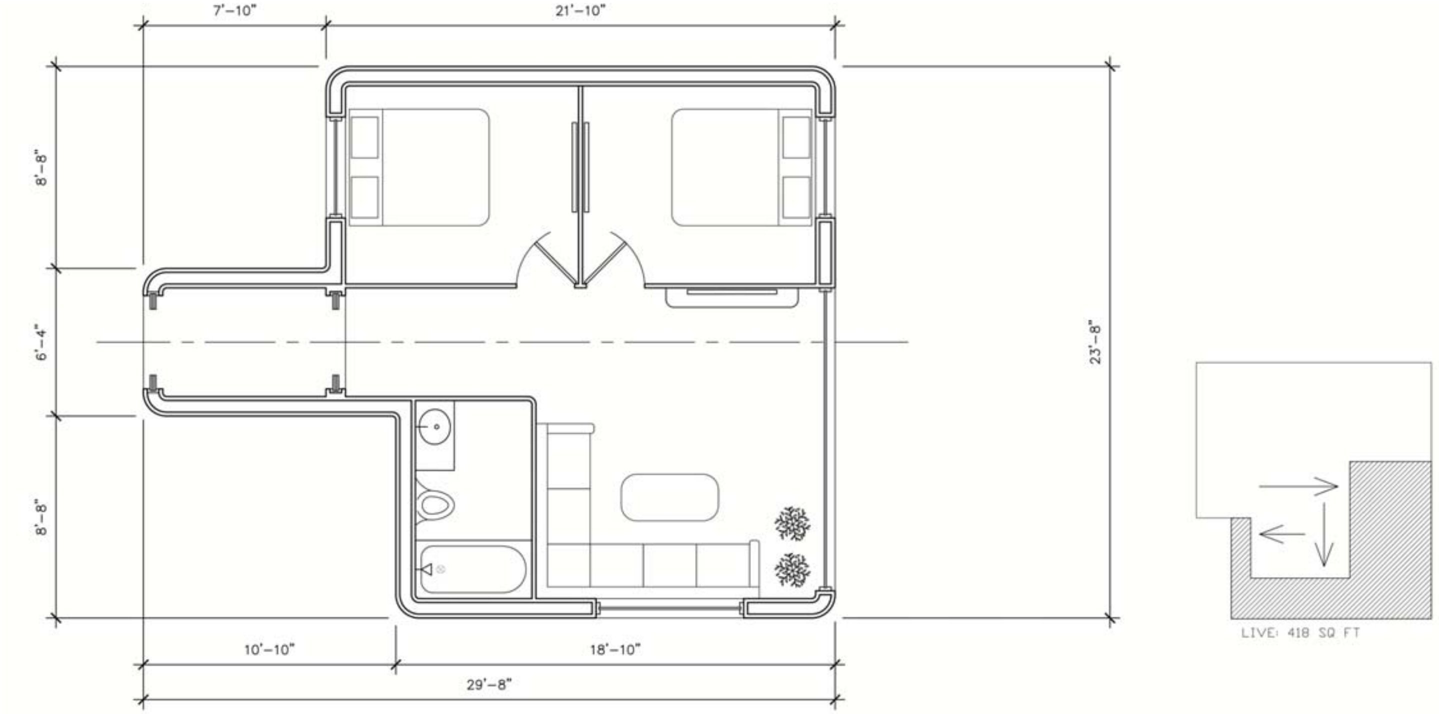


Figure 6.18 Plan, double- live

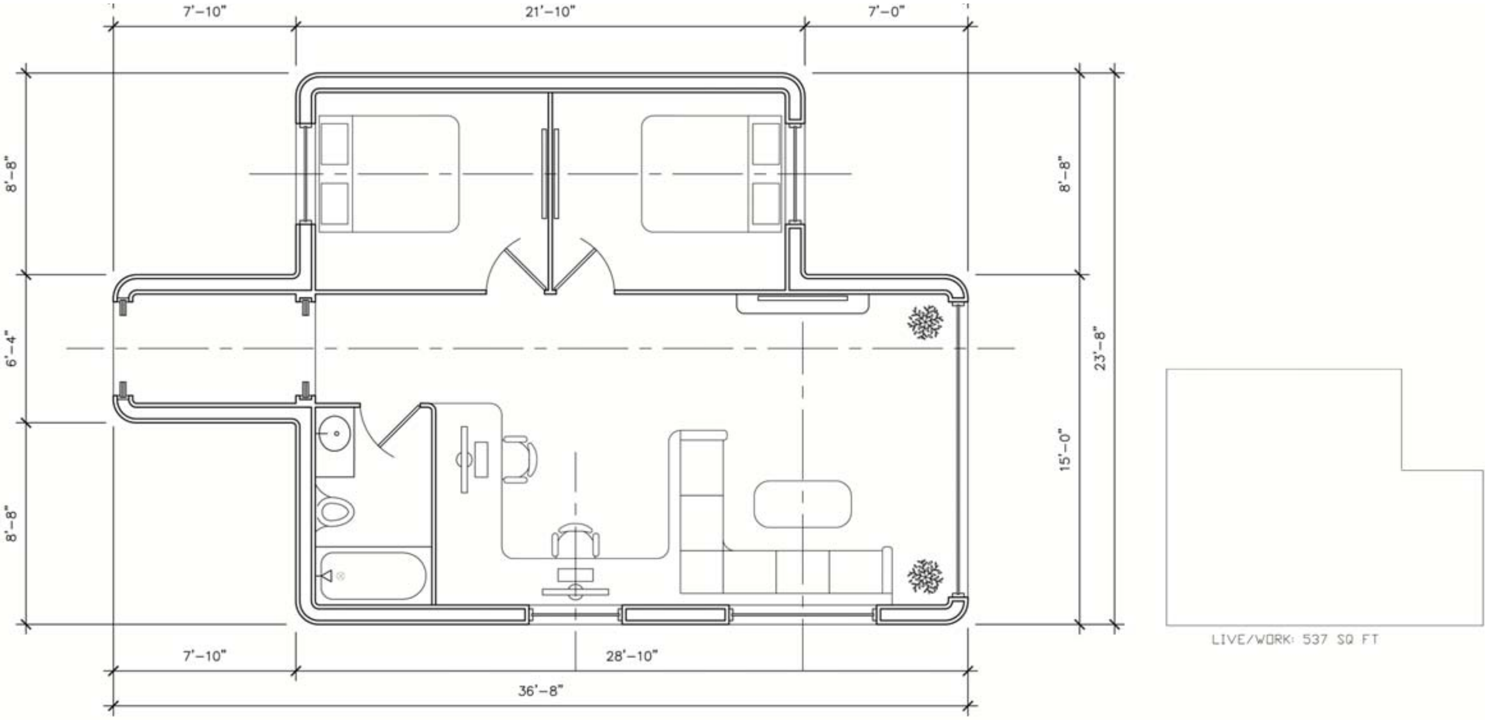


Figure 6.19 Plan, double- live + work

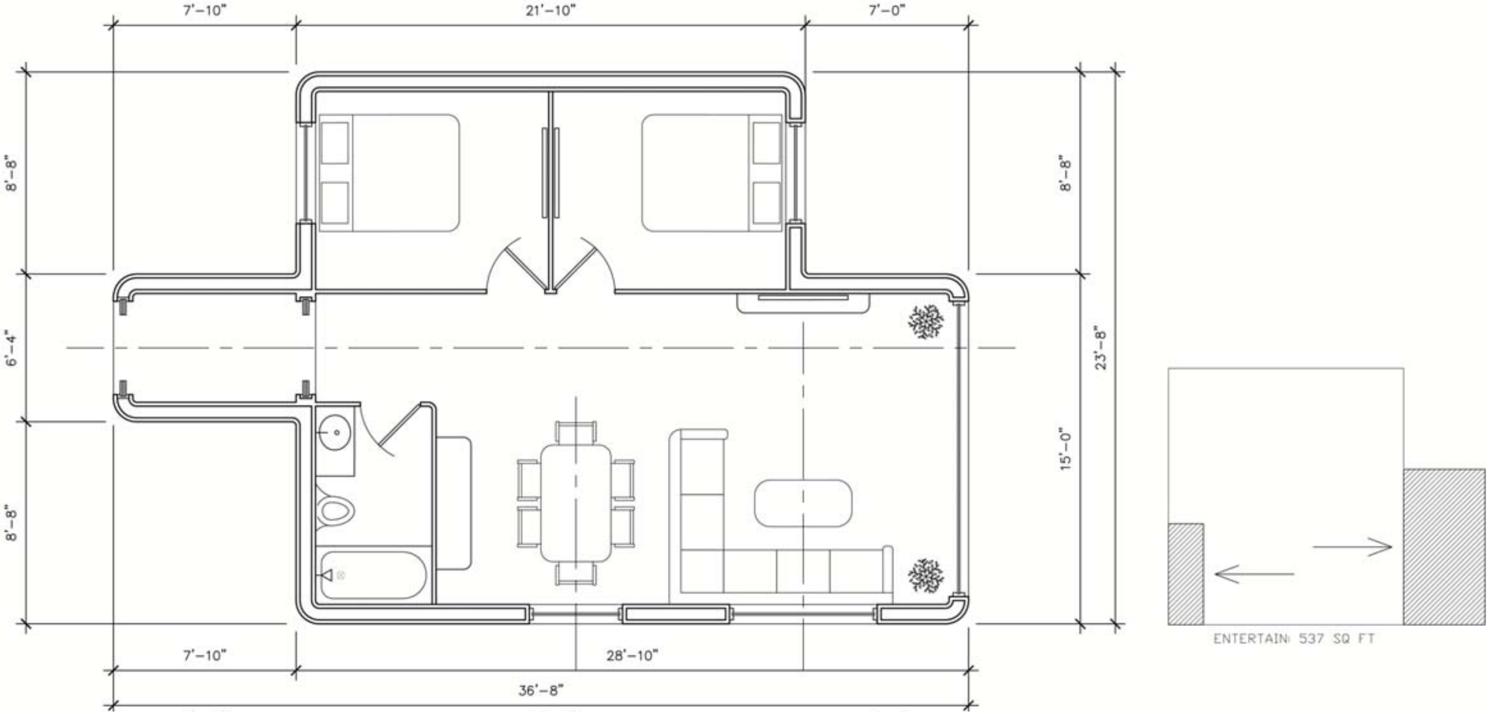


Figure 6.20 Plan, double- entertain

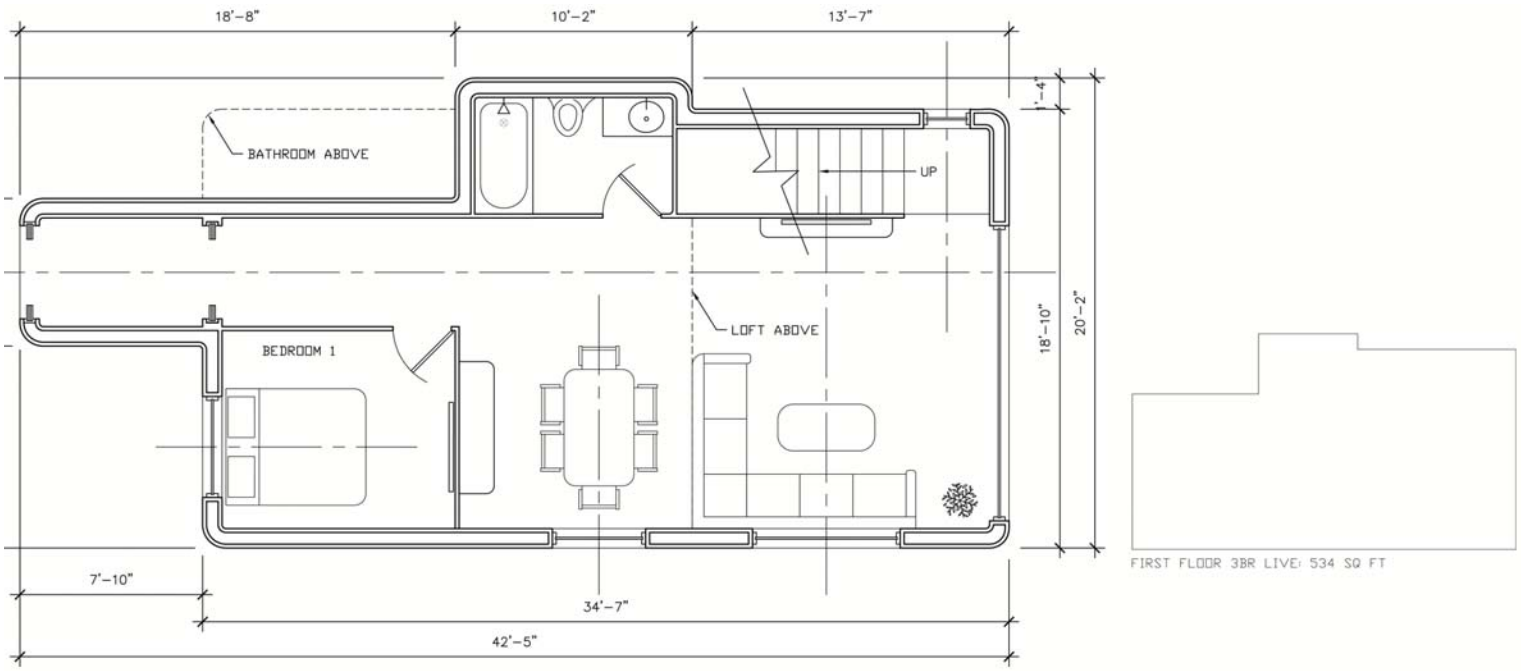


Figure 6.21 First floor plan, quad- live

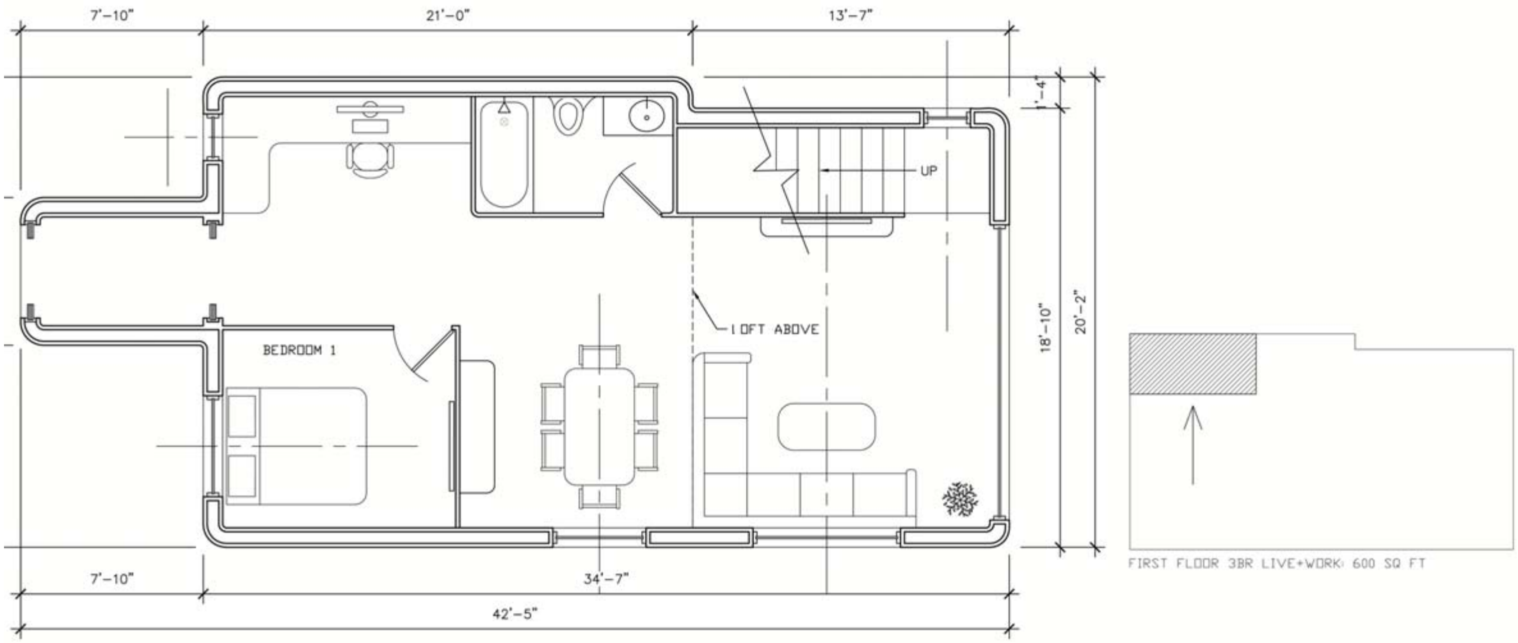


Figure 6.22 First floor plan, quad- live + work

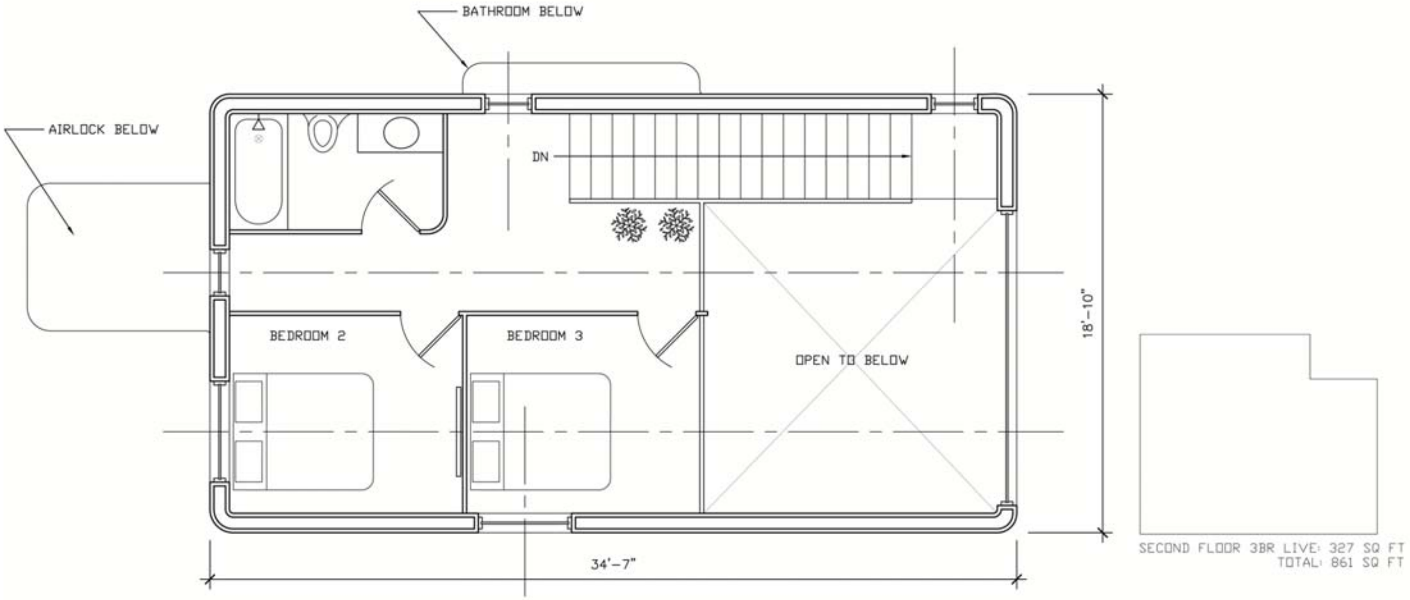


Figure 6.23 Second floor plan, quad- live

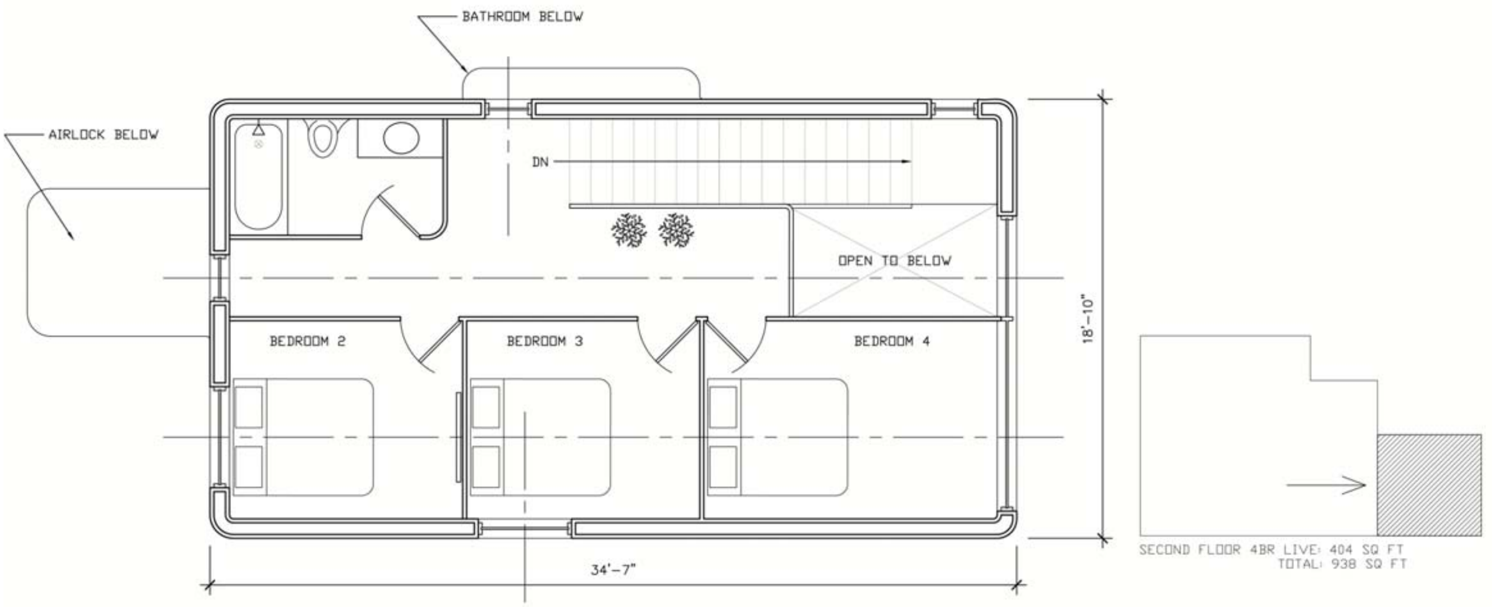


Figure 6.24 Second floor plan, quad- expanded

Figure 6.25 Plan, residential wing

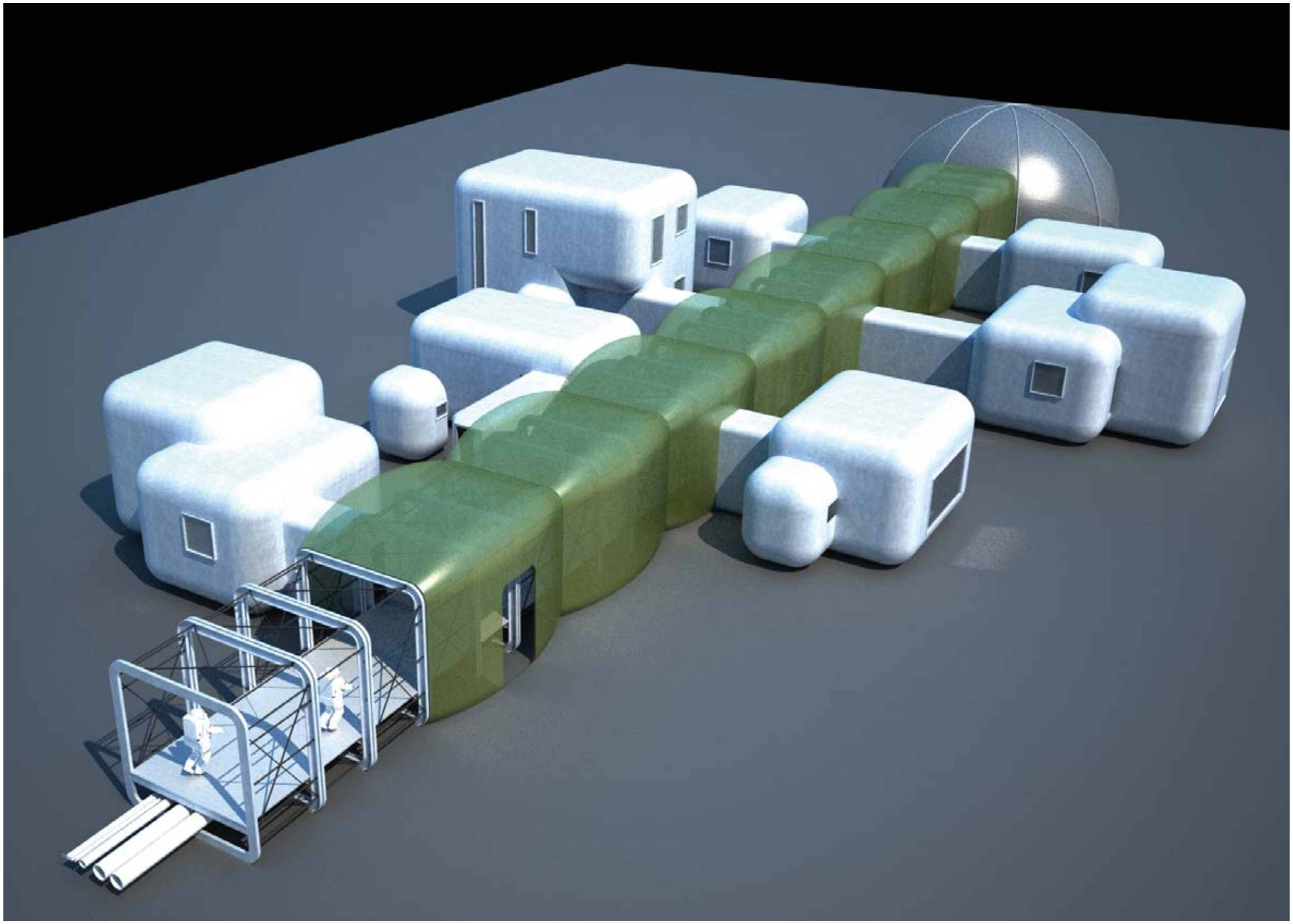


Figure 6.26 Aerial perspective, residential wing

6.3 Circulation modules

The circulation modules are the spaces connecting all of the other modules. Analogous to corridors or hallways on Mars, the circulation modules connect the infrastructure and life support systems of the settlement and provide continuous pressurized spaces connecting the entire settlement. These spaces are occupied only temporarily and as a means of travel from one part of the settlement to another. Because of this temporary occupation, inflatable lightweight materials attached to rigid metal frame were designed as a structural/skin system. Figures 6.27- 6.32 show the design of the circulation modules in greater detail .

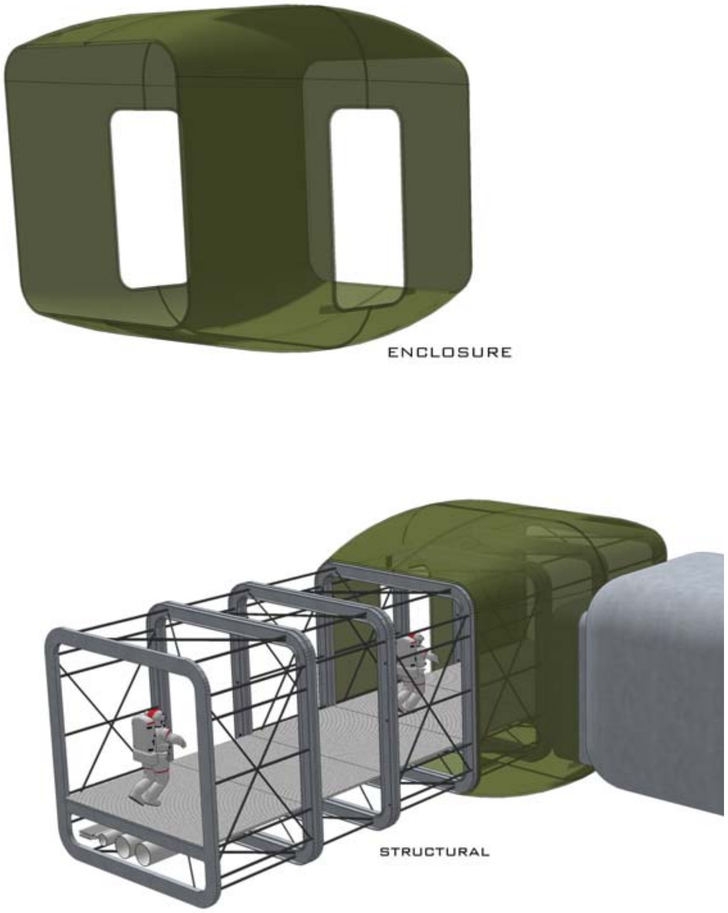


Figure 6.27 Exploded axonometric

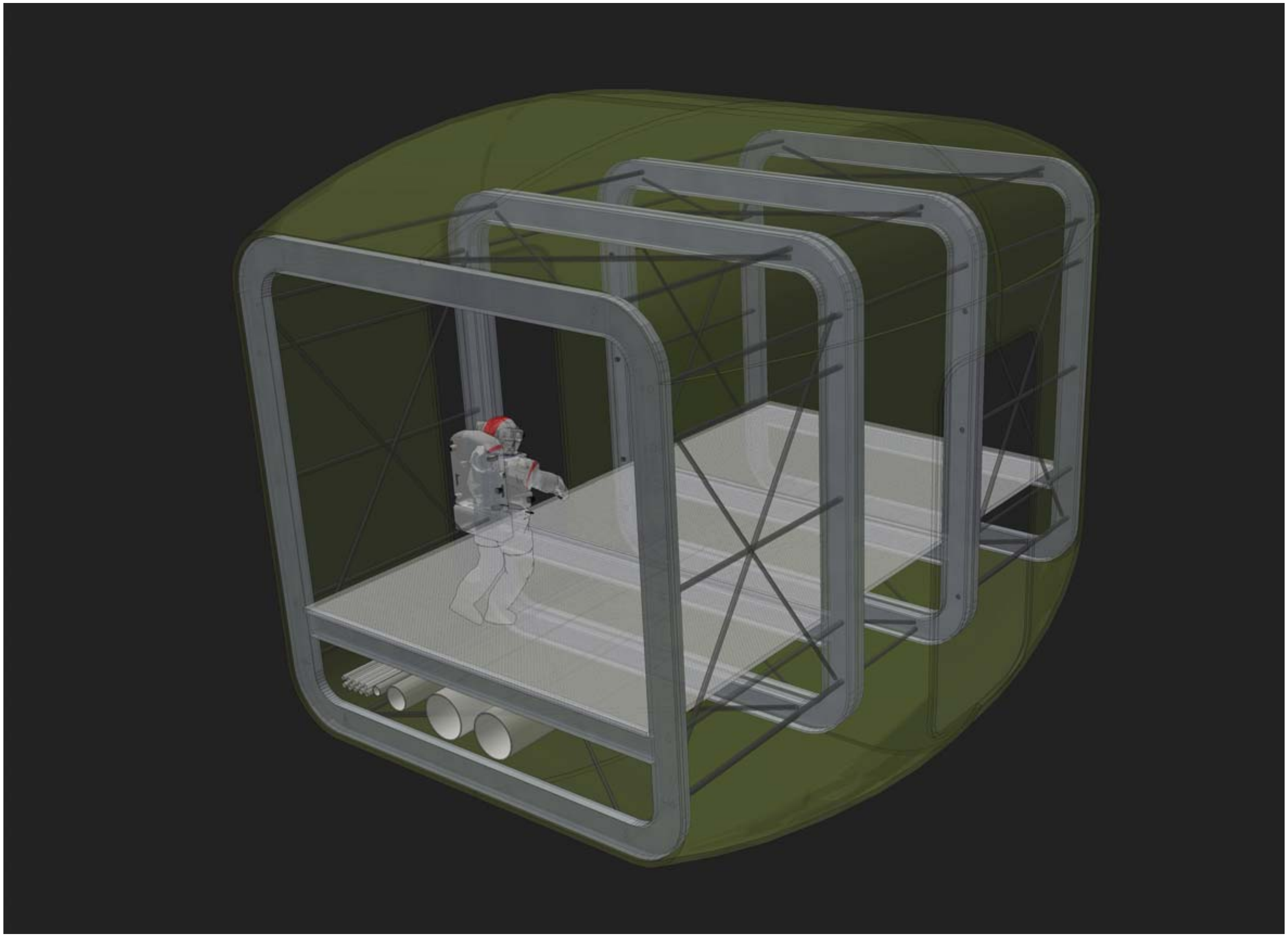


Figure 6.28 Circulation module

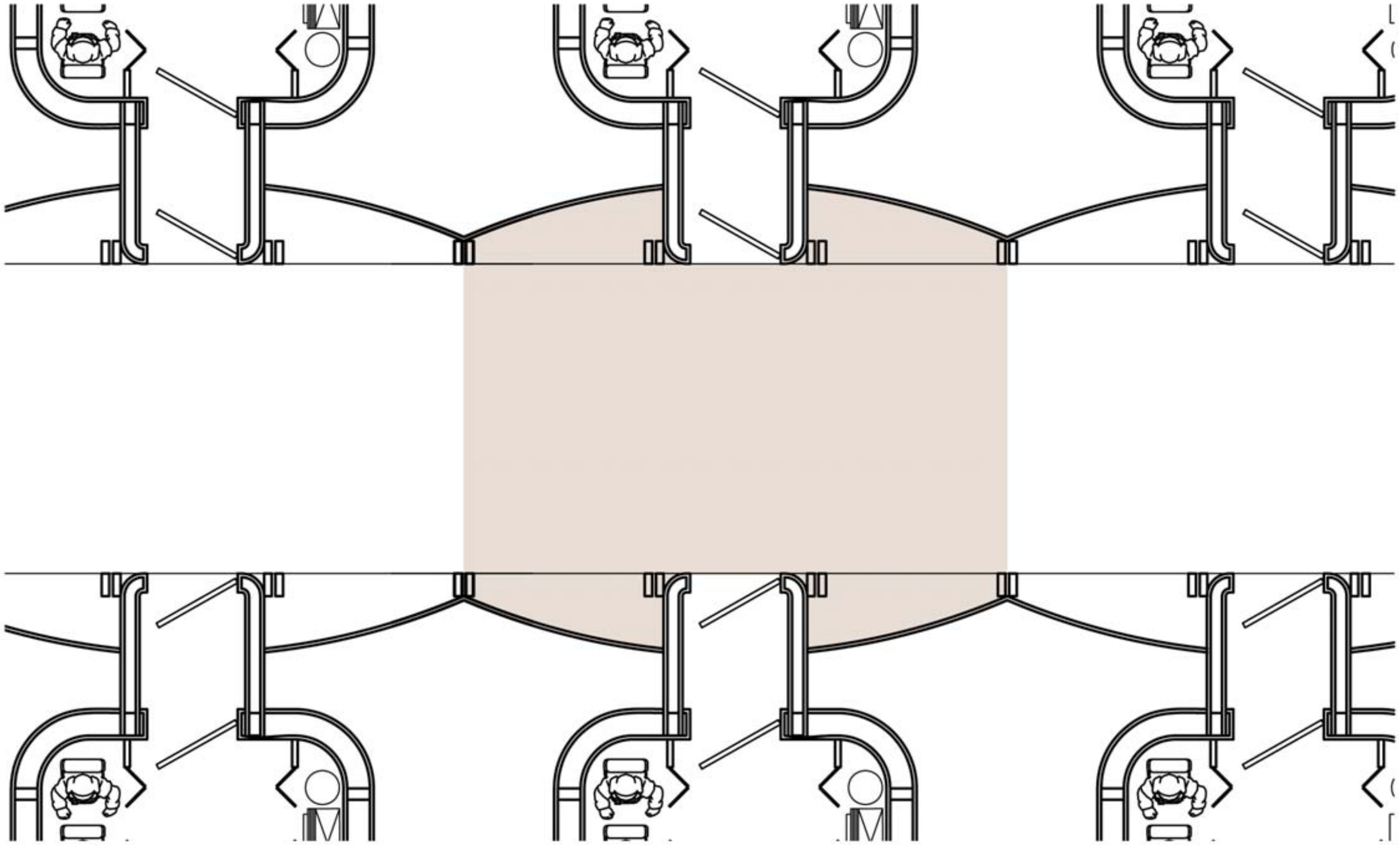


Figure 6.29 Plan, circulation module

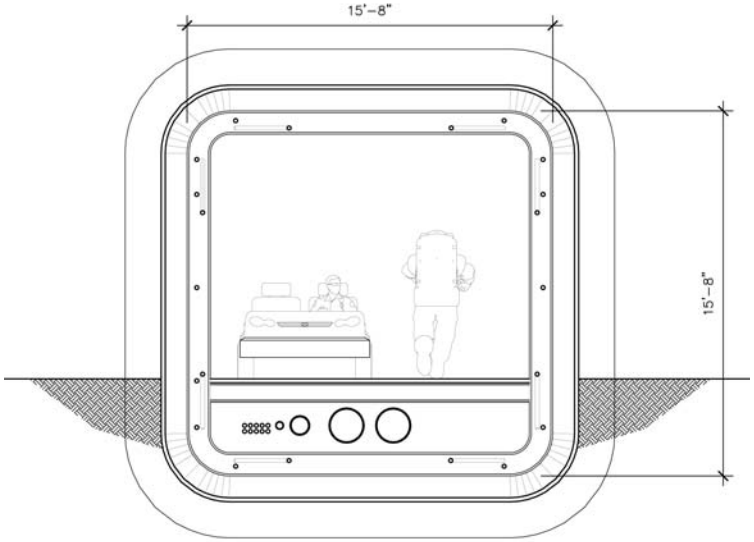


Figure 6.30 Section, circulation model

Figure 6.31 Rapid prototype

Figure 6.32 Interior perspective

6.4 Greenhouse modules

The greenhouse modules are necessary to provide nutritional subsistence for all of the settlers. 1000 square feet must be provided per person in hydroponic gardens. To minimize the architectural footprint of the settlement, these gardens are stacked vertically, reducing the greenhouse footprint per person to 500 square feet. Because they are minimally-occupied by people, the greenhouses can also be inflatable structures. Transparent materials will benefit plant growth, but artificial lighting will also be necessary to maximize agricultural output.

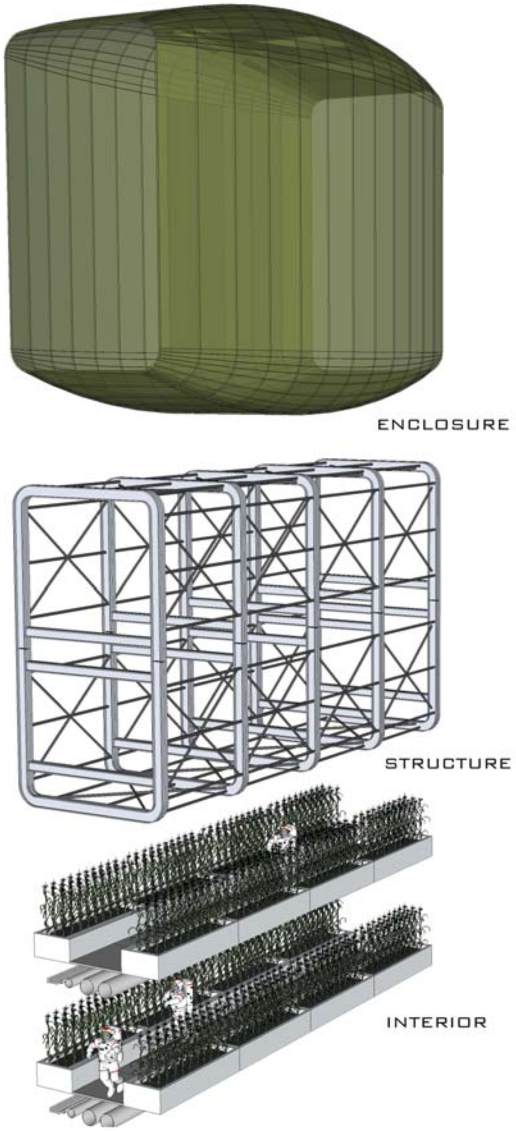


Figure 6.33 Exploded axonometric

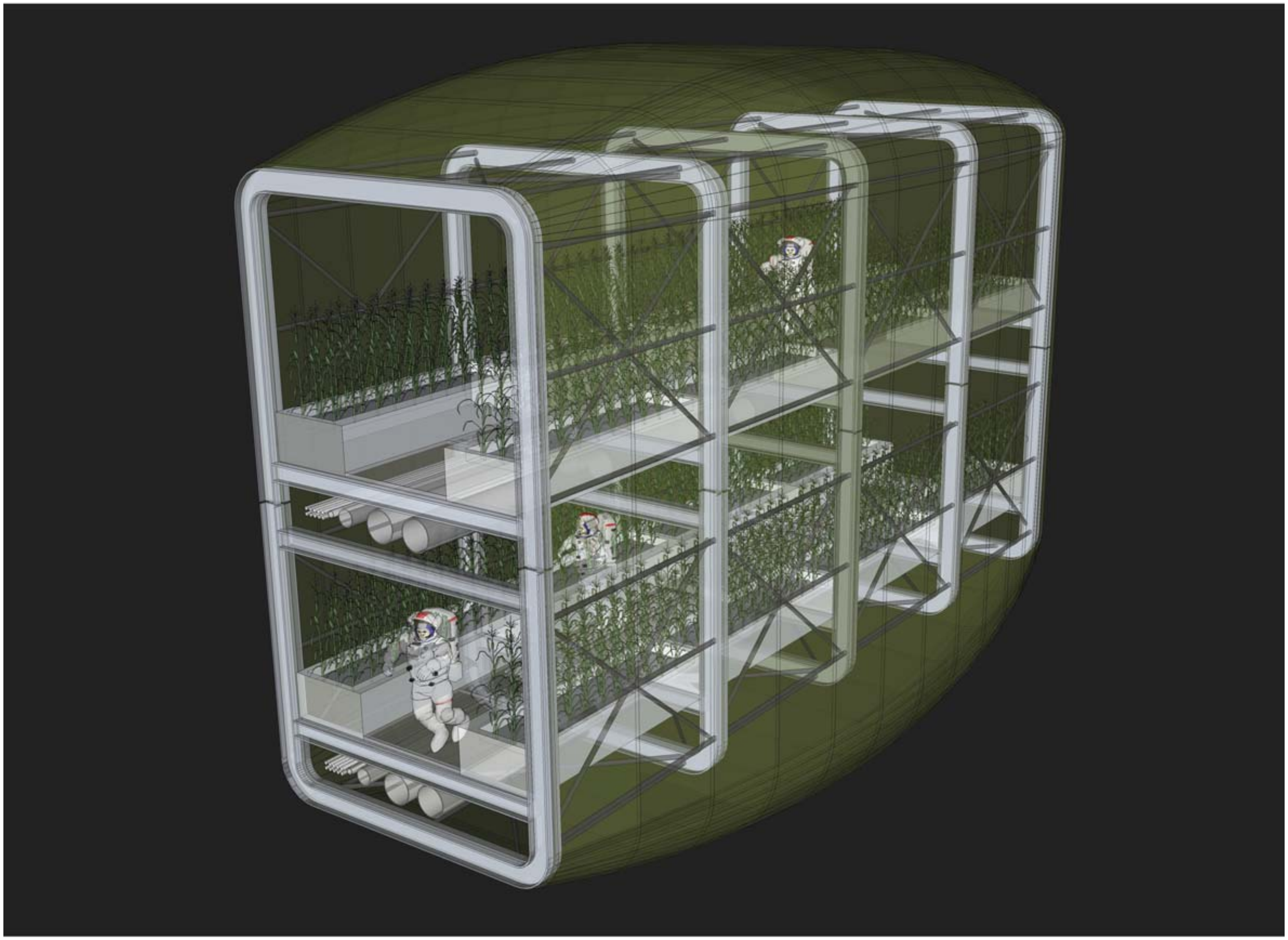


Figure 6.34 Greenhouse module

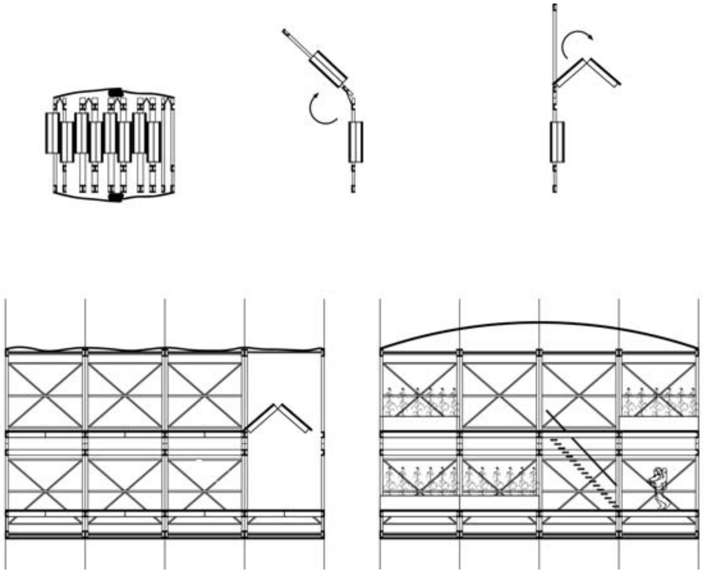


Figure 6.35 Greenhouse assembly

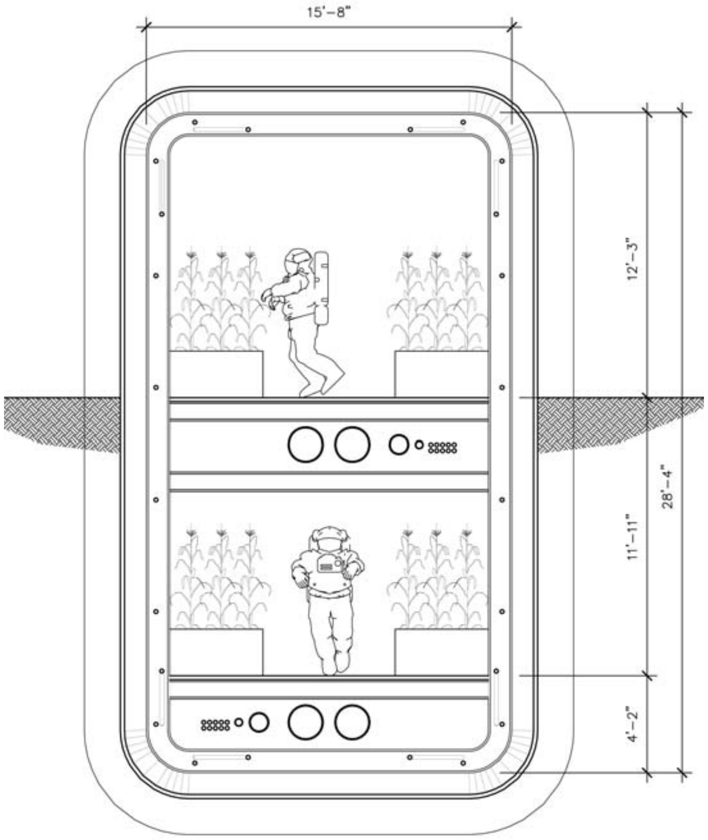


Figure 6.36 Greenhouse section

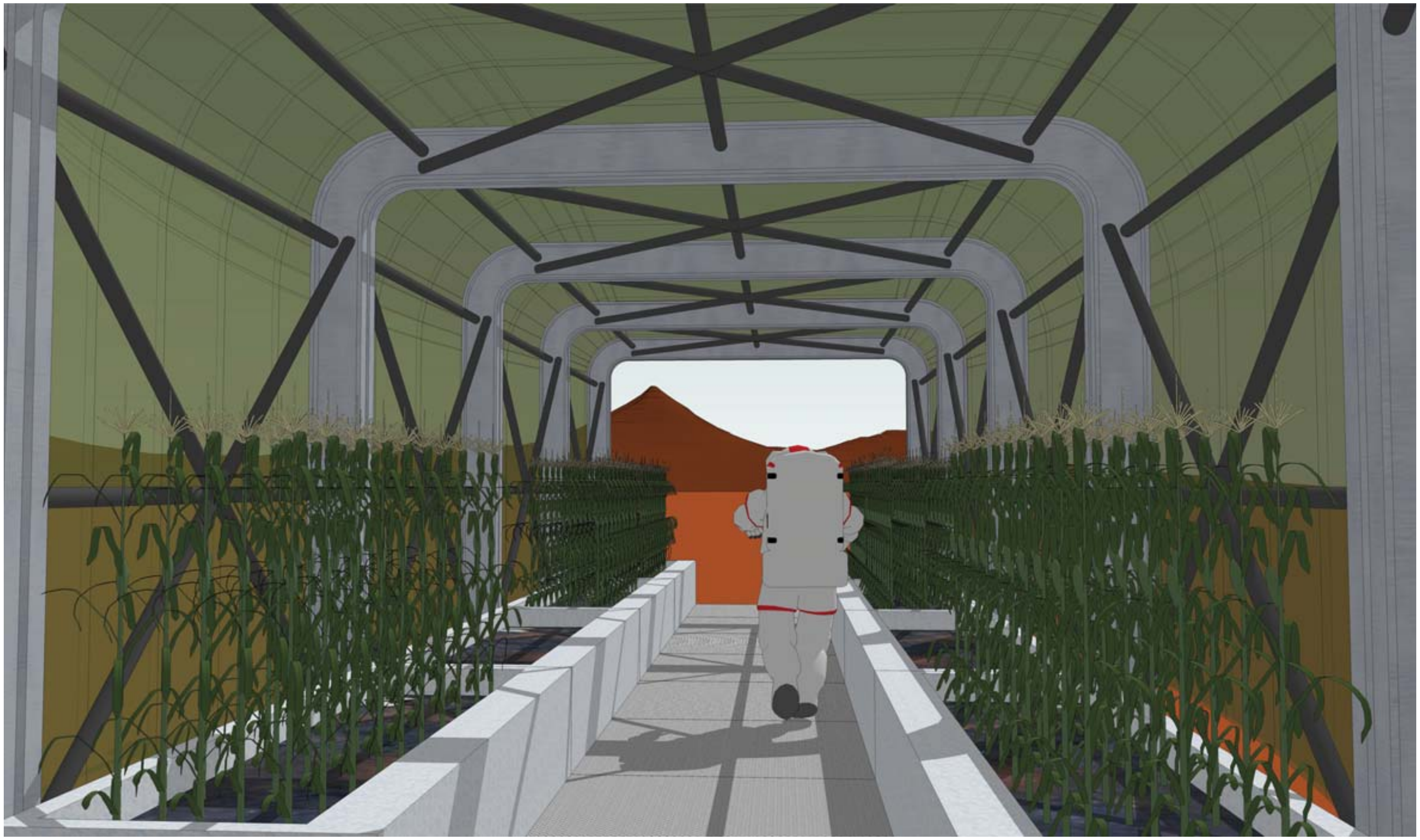


Figure 6.37 Interior perspective

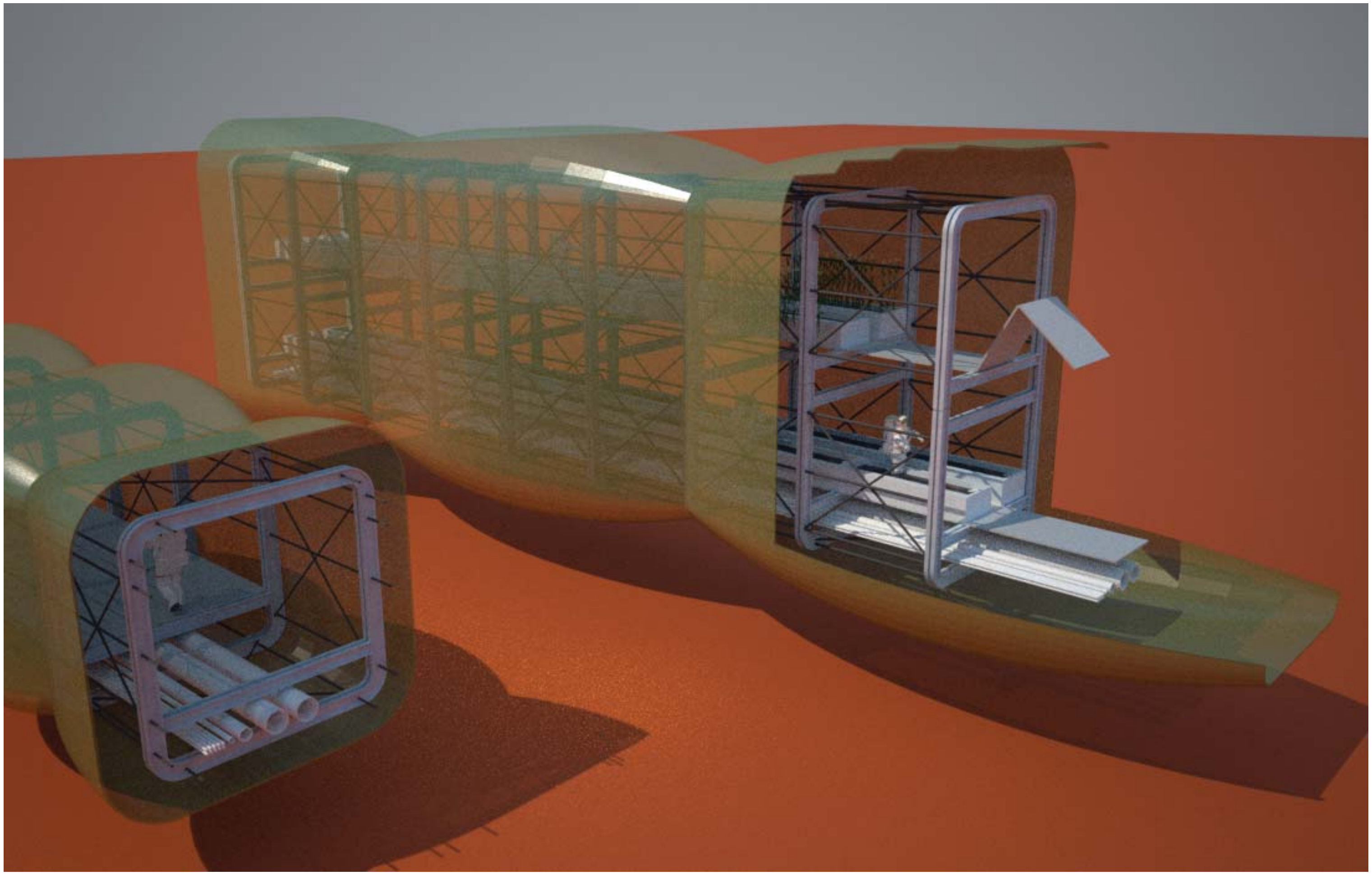


Figure 6.38 Aerial perspective

6.5 Entertainment modules

The entertainment modules are larger, social spaces where people meet, socialize, and relax. Qualities of both indoors and outdoors are desirable, and flexibility of space is necessary. Because of the size of these spaces, and programmatic needs placed on them, lightweight inflatable domes were chosen to contain the entertainment spaces. A carbon nanotube structure provides rigidity in the event of a breach in the surface of the domes while nanorobots repair the damaged area. Over the next 40 years, materials will be developed that both shield the occupants from harmful radiation and allow sunlight to illuminate the spaces. Photovoltaic cells are embedded between layers of polyethylene, and micro wind-turbines are mounted to the exterior surface of the domes.

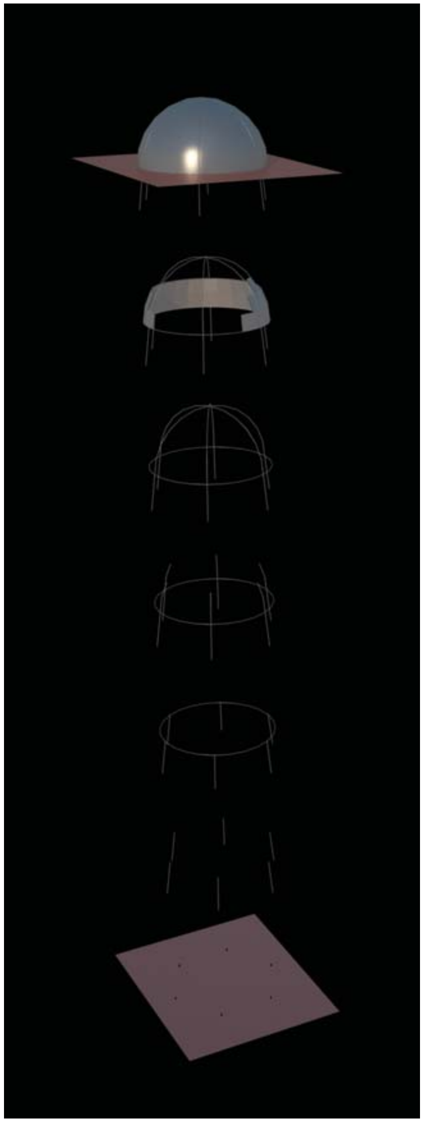


Figure 6.39 Dome assembly

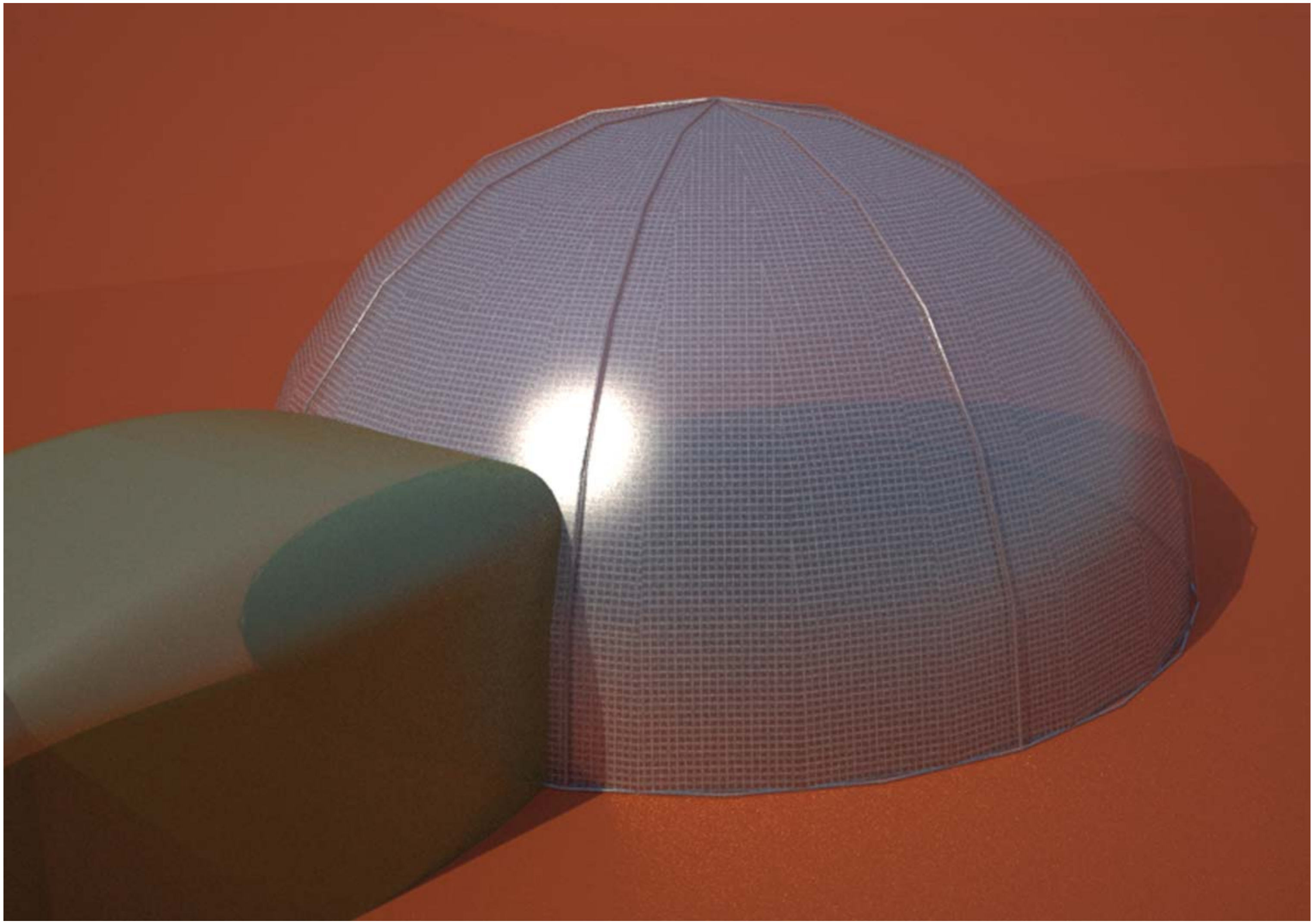


Figure 6.40 Entertainment module

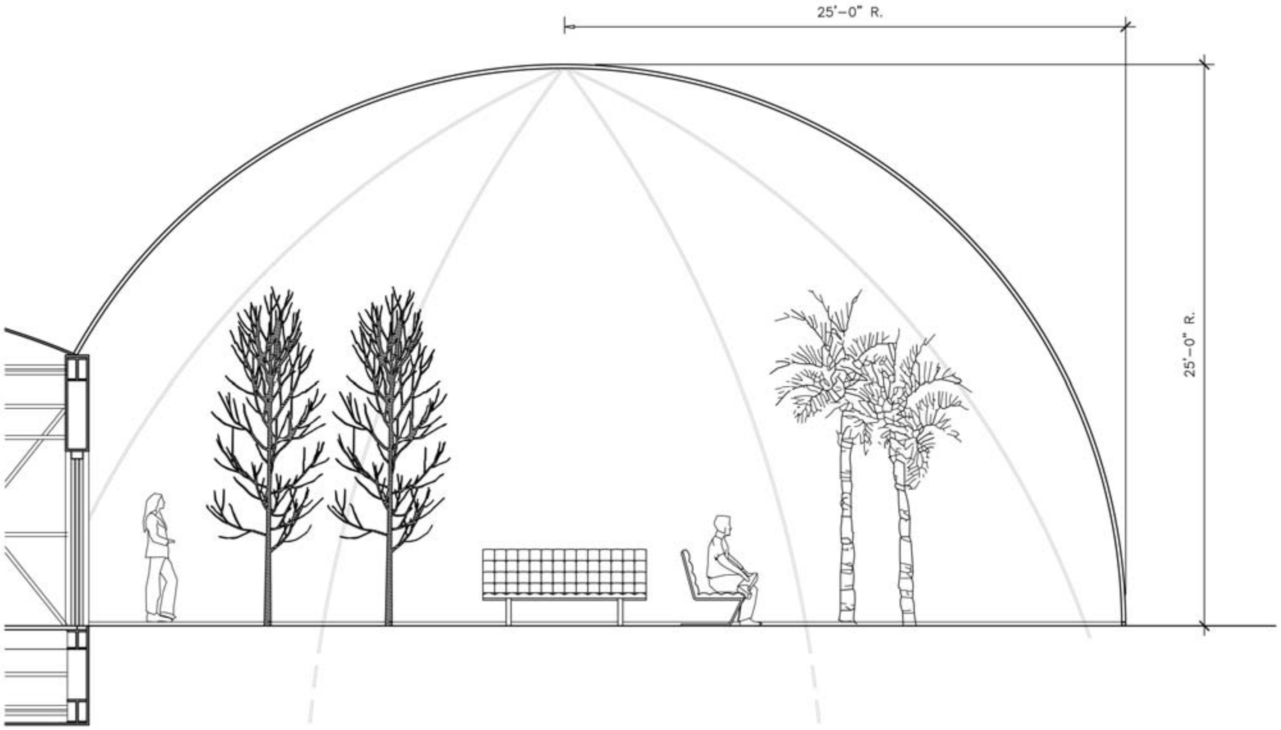


Figure 6.41 Section, entertainment module

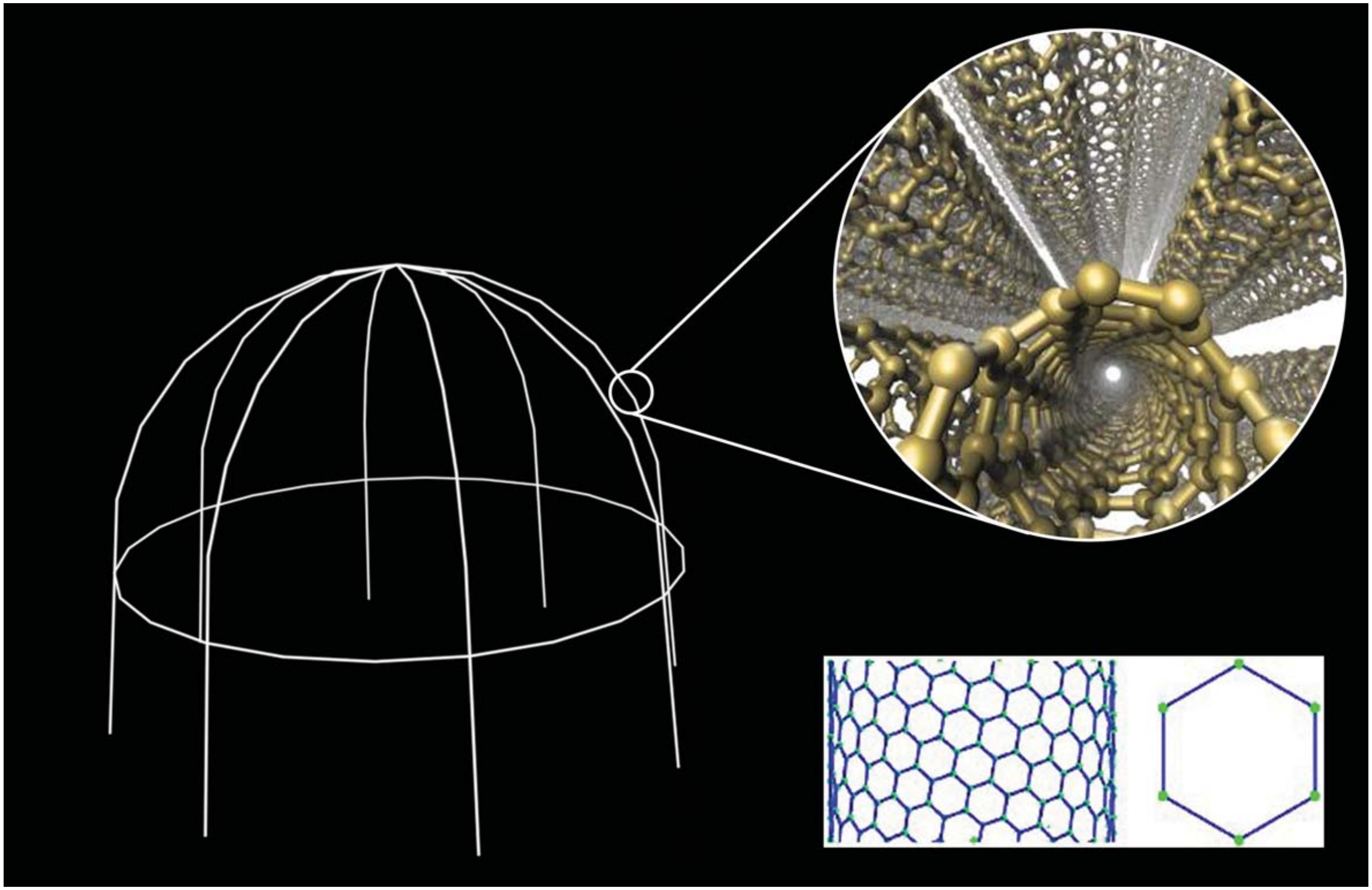


Figure 6.42 Carbon nanotube structure

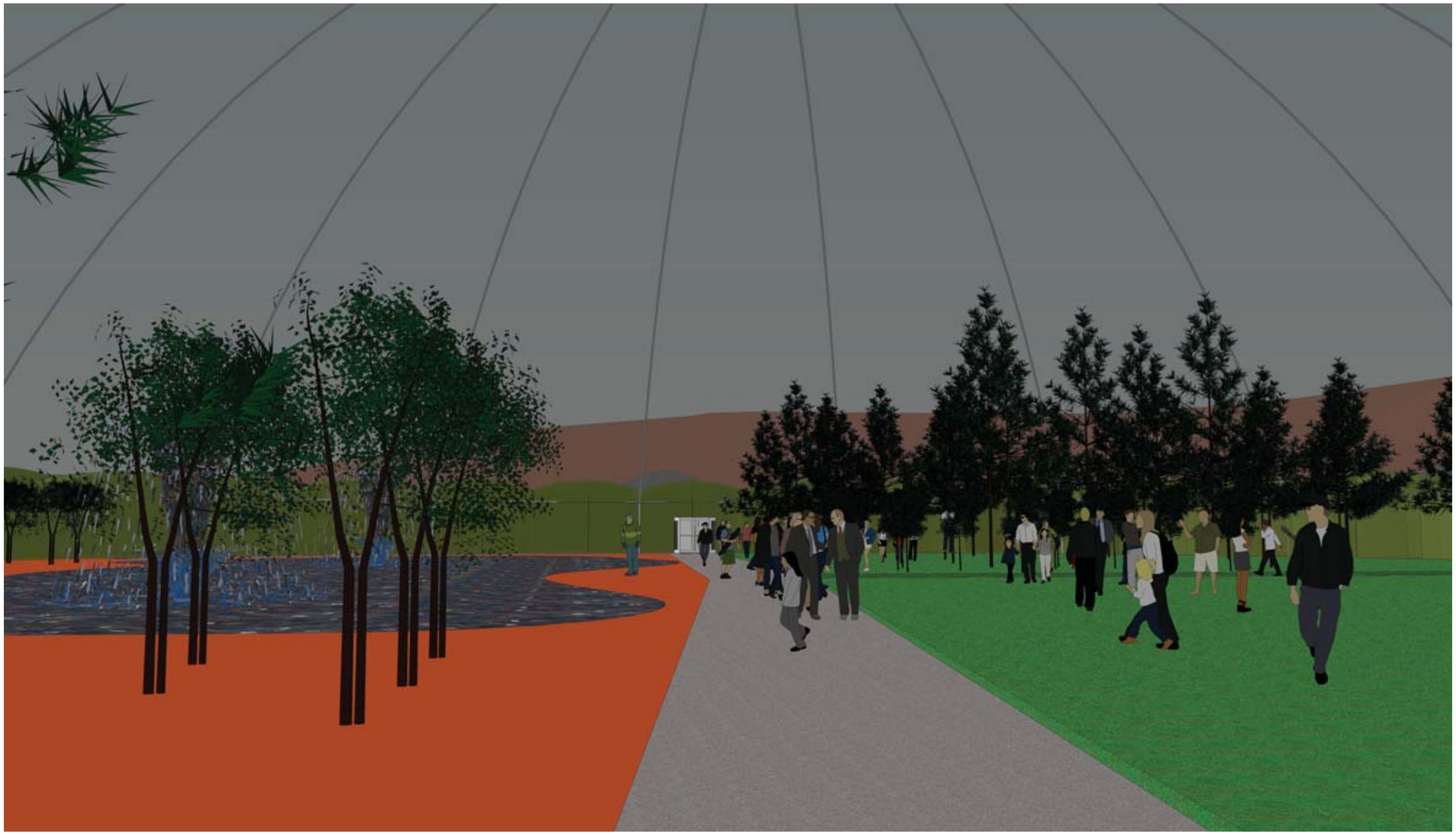


Figure 6.43 Central Park

6.6 Sustainable strategies

Sustainable design and practices are an essential aspect of the settlement; the settlers cannot be dependent on resources delivered from Earth, and must be able to provide for themselves all of the resources and materials necessary for survival.

•Wind power will provide electricity to the settlement from a wind farm located at the western point of Husband Hill (Figure 6.44) to take advantage of prevailing winds. Micro wind-turbines will also be attached to the surface of the domes.

•Solar power will provide supplemental energy, with photovoltaic cells embedded between layers of polyethylene, with also serves to shade the spaces within the domes. By locating the settlement at a near equatorial latitude, the exposure to incoming sunlight is optimized (Figure 6.45).

•Nuclear power will provide a backup redundant power source in the event of an emergency. Surplus energy will be stored in banks of high-capacity batteries.

•Water will be the most essential resource for extended stays on the Martian surface. New data consistently increases the estimate water reserves. The NASA rover *Spirit* confirmed the existence of liquid water near Husband Hill, and for the purpose of this project, it is assumed that there is a vast glacier buried beneath Husband Hill. Water will be mined to provide all of the needs of the settlement, including

Figure 6.44 Wind power

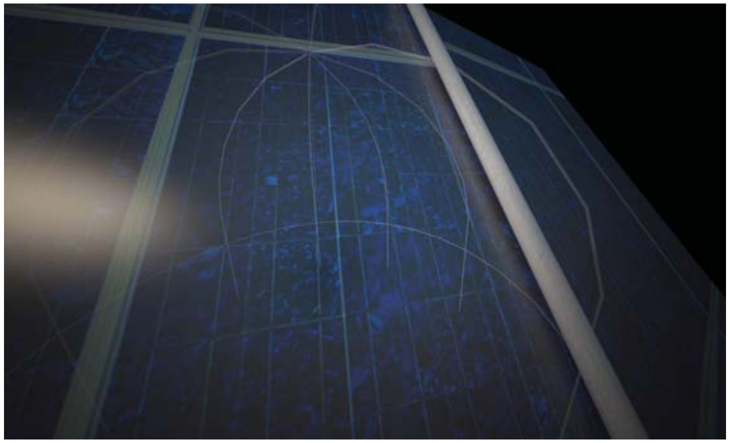


Figure 6.45 Solar power

agriculture, water for drinking, and life support systems.

•All of the water will be reused in a self-filtering closed-loop system using a created wetlands in the central park. The treated greywater will be used to provide water for all of the agriculture, landscaped areas, and sinks/toilets (Figure 6.46).

•Inflatable greenhouse modules will provide all of the food resources the settlers consume, and the labor of farming will be divided equally. 1000 SF per person is allotted for hydroponic gardens.

•All organic waste will be recycled and/or transformed into fuel and/or building materials.

•Chemical plants and robotic mining machines will harvest volatile elements from the atmosphere and surface to provide raw materials for use in construction and life support systems (Figure 6.47).

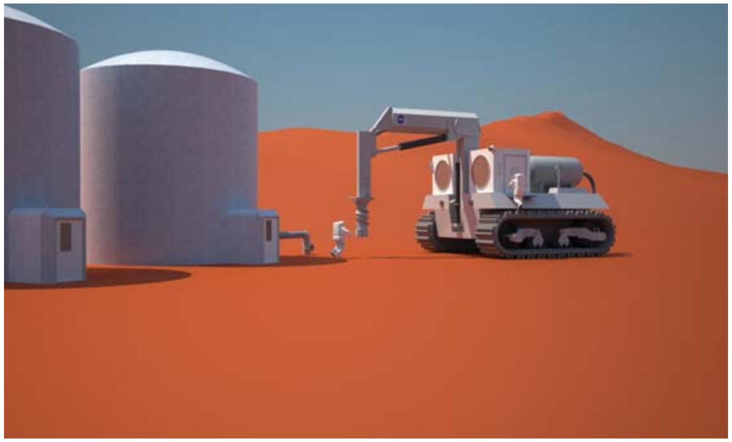


Figure 6.46 Resource mining

Figure 6.47 Water recycling

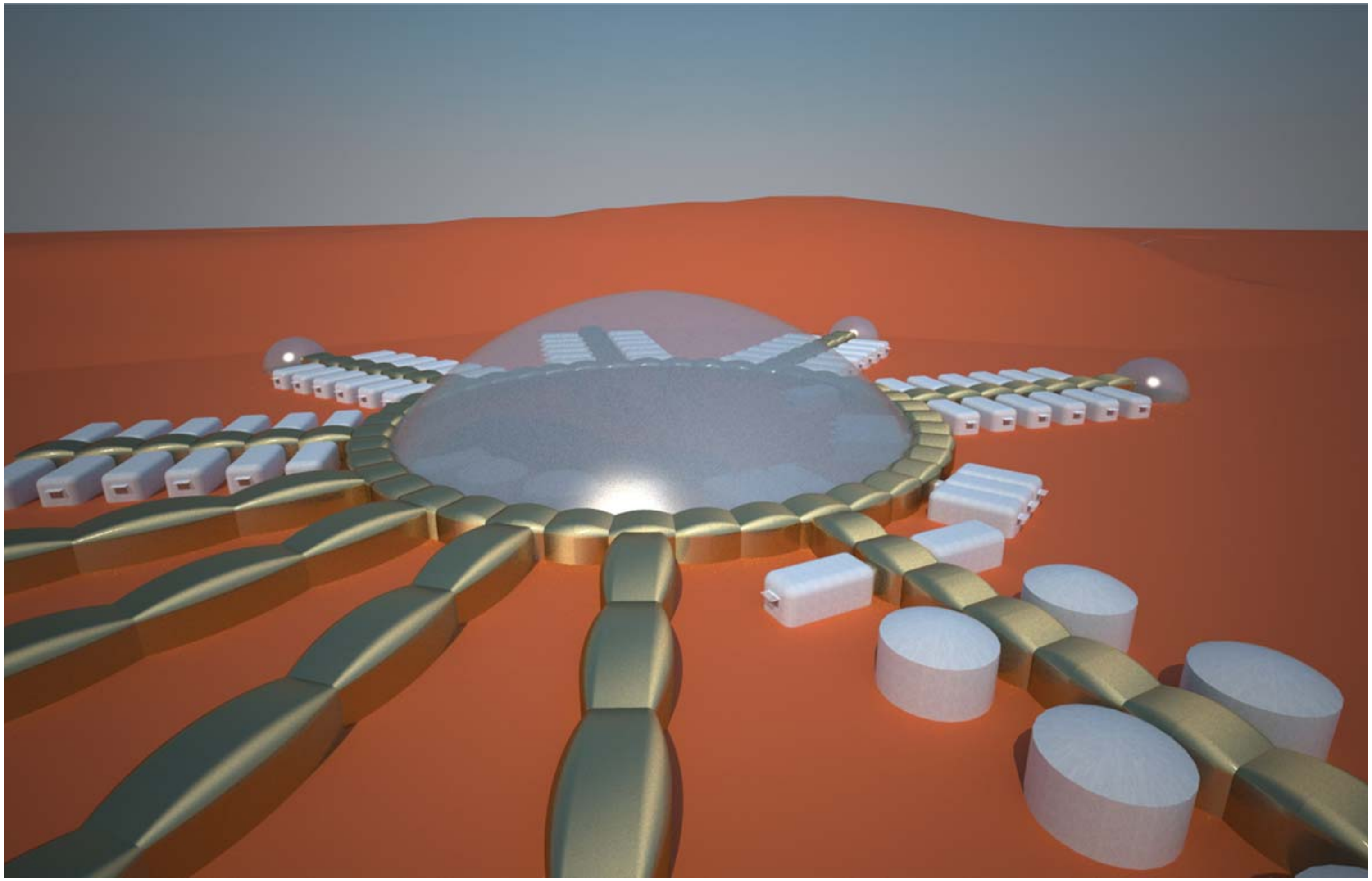


Figure 6.48 Final rendering

7. CONCLUSION

The conclusion of this project and author is that technology will change everything. What began as a project investigating how Martian settlements in the year 2050 might be designed and built led to the discovery of an impending technological revolution that transformed the conceptual approach. Knowledge gained from research into emerging technology confirms that people will be able to live comfortably on Mars, in ways impossible to imagine when constrained by the limits of our present capabilities. Assuming the technologies described in this project are developed over the next 40 years, the concept of a completely programmable self-constructing permanent settlement on Mars is no far stretch of the imagination.

Nanotechnology and programmable matter has the very real possibility of changing the way everything is done, and the architectural implications are mind numbing. The idea of programmable space, structures made entirely from programmable matter, may be the most profound concept taken away from this project, and a possible area of future research. Further development of this project would also include a focus on designing more socially engaging residential areas, to create a greater sense of community or neighborhood, and a greater exploration of the programmable entertainment spaces.

The hope of this project is that certain ideas and concepts will be developed and used in future space architecture. Emerging technology will enable people to live comfortably on Mars, and beyond.

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