Gdańsk University of Technology
Faculty of Architecture
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Doctoral thesis

Architectural problems of a Martian base design as a habitat in extreme conditions

Practical architectural guidelines to design a Martian base

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Abstract

Manned mission to Mars is a particular case of space missions due to its long-term duration. A human factor becomes here as important as technological problems are. The author argues that people cannot stay for over two and a half years in a confined and uncomfortable capsule (as among others a NASA Reference Mission proposes). A human-friendly habitat appears to be crucial here. Bigger crews present less deviances than smaller ones in ICEs - as sociopsychologists' survey indicates. Therefore, for a bigger crew a larger living space should be designedMartian base. **The extreme Martian conditions require a specific architectural design.** Comprehensive analysis of this problem has been performed in the dissertation. The author concludes that **the current knowledge about Mars, along with contemporary building technologies, enable to design different human-friendly habitats on the Red Planet**. The evidence to support this statement are several author's architectural models presented in this dissertation. Physical and psychological comfort of the extraterrestrial base inhabitants can be significantly enhanced by proper architectural design. The author presents here her conceptual design of the Martian base as an example of the relatively low cost solution for a safe, aesthetic and human-friendly extraterrestrial habitat, that can be developed due to future needs.

The Martian base is a particular example of the habitat in extreme environment. Different issues considering this special type of the habitat are thoroughly investigated in this dissertation. The first section is focused on the current plans of manned space missions proposed by space agencies all around the world. The author shows assumptions that have positioned the way of her researches. In the second section the objectives, the way of conducting, and methods of the researches and thesis of the dissertation are described. In the third section, the author shows Mars as a specific building site. The specific conditions are shown as the factor influencing the construction and the shape of the habitat, that is concreted in the conclusion of the dissertation. The fourth section describes the influence of a human factor on the architectural design of Martian base. The analyses of the survival problem, socio-psychological conditions, physical and psychological comfort issue have led the author to the meaningful conclusion about the design of Martian base. In the fifth section, the cross-section analyses of different existing habitats in different extreme conditions on Earth, and in the outer-space, similar to Martian one, are conducted. The review has proved valuable to assess hitherto verified architectural solutions in the matter of interest. In the sixth section the habitat's architecture is described in the points titled: “construction”, “shape”, “function” and “interiors”. The existing building technologies, which have been accepted as best to adapt into extreme conditions, have been analyzed. The question of the shape of the base considering the influence of available technological solutions has been discussed along with the problems of possible dimensions of the base, as well as the the question of human factor. A problem of the design of a functional arrangement in Martian base, some solutions for interior

design (considering the restrictions for the construction), the shape and the functionalism of the habitat—all of those problems are elaborated here for the search of possible answers. On the basis of the section number six there have been worked out four exemplary solutions by the author. The concepts of extraterrestrial bases described in literature have been critiqued analytically in the fifth point of this section. In the seventh section the author describes her own architectural concepts of the Marian base which comply with all the eligibility criteria defined in conclusions of previous sections. One of the models is elaborated in the eight section of this dissertation.

In sections three, four, five and six the author conducted several analyses on the basis of 189 items of available scientific literature. Extrapolated by the author “conclusions for architect” (200 of them) which are the guidelines for the designing of Martian base finish the analyses. All of the nine of the architectural models and the concept project are the author's own proposition worked out on the basis of the guidelines mentioned above.

Note from the editor: in some places the translation may be incomplete (e.g. a not translated picture or language errors). If any inconsistencies were found please report to j.kozicka@gmail.com with email subject line “Martian base PhD, translation mistakes”.

The original can be found under address:

http://janek.kozicki.pl/phdthesis/kozicka_2008_PhD_pl_lowres.pdf

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1 Introduction

1.1 Origins of the topic

The manned mission to the outer-space began in the 1960s of the 20th century. The exploration and colonization of the Universe, possible with contemporary technologies, are the reason to conduct scientific researches in the different fields of science and engineering. Thanks to it the best solutions to implement the big objectives are being gained to know better and to establish settlements in the Universe.

To the present time people have landed on the Moon only, the natural satellite of Earth. It has appeared to be an inhospitable place, dry, empty, deprived of any atmosphere; a very low gravitation makes moving around very difficult. There are completely strange environmental conditions for humans on other planets and moons, and human beings are not adjusted to them. There is a possibility to *terra-form* such places, which means reshaping those celestial bodies to make proper life conditions. However, the process is always very long, complicated and dangerous, as well as introduced transition may influence the virgin scenery irreversibly. If that is the case, there should be built artificial hermetic ecosystems, where people could safely live and work. The dimensions of those ecosystems could probably relate to the size of a city. There is also an idea of creating settlements in the Space itself, as well as in the insides of planetoids. Nevertheless, regarding contemporary capabilities, the most rational decision seems to be the colonization of Mars. There are many reasons to this, where the most important seems to be gravitation, which is the most similar to the Earth's gravitation (1/3*g*, when the gravitation on the Moon is 1/6*g* only, and in the Space 0*g*), and the existence of some different local resources, counting water as the most important one. Mars is only the third closest to the Earth celestial body. However, the temperature is not as extreme as on the Moon, which is deprived of atmosphere, and on the hot and volcanically active Venus.

The popular belief is that any kind of extraterrestrial colonization of other planets belongs to science-fiction. In the meanwhile the first manned missions to Mars are planned for the years 2025-2030 (Tab.1.1). The first schemes of the Universe exploration have been worked out considering establishing first human settlements in the outer-space. They are prepared by scientists of different space agencies from many countries. One of such programs is *Mars Direct*. It has been established during the *Case for Mars* conference, and its assumptions were published for instance in Zubrin's and Wagner's “The Time of Mars” (1997). This is the fastest, the safest, the most factual, and the cheapest program of the exploration of the Red Planet and creation of a settling there. It states that every three years there should be a manned mission organized, only when there a suitable position of both of the planets, Earth and Mars. The first one to send should be a coming-back module for the first mission. After the landing in a chosen place on the surface it should start fuel production, from hydrogen transported from Earth, and from proper local resources. Thanks to that possibility, there would be no need to build a huge space shuttle on the orbit of Earth, and no need to collect reserves for the mission from it.

Table 1.1 Plans of World Space Agencies, connected with human exploration of the Moon and Mars

Space Agency	The Moon	Mars	Acknowledgements
NASA United States of America *National Aeronautics and Space Administration*	2015 – 1st Manned mission (at the latest 2020)	Human exploration of the Moons is to be the preparation to mission to Mars (around 2030)	"The Vision for Space Exploration" (NASA 2004b)
ESA European Countries *European Space Agencies*	2024 – 1st Manned mission	2030 – sending a habitat module 2033 – 1st Manned mission	"The Aurora Program Brochure" (ESA 2004)
JAXA Japan *Japan Aerospace Exploration Agency*	2025 – 1st Manned mission and start building a base		"JAXA Vision Summary" (JAXA 2005)
CNSA China *China National Space Agency*	2020 – 1st Manned mission		"China Plans Manned Moon Mission by 2020" (CNSA 2003)
4Frontiers Corporation *A private corporation*		2025 – building a base on Mars using local resources	"Mars Settlement Design" (4Frontiers 2007)

One mission would last about 2.5 years, which is 6 months one way, 1.5 year on the planet, and 6 months to return. The technological solutions to accomplish the program are available today, and thanks to that the program *Mars Direct* has been approved by NASA; on the basis of the program *Mars DRM, Mars Design Reference Mission,* the program of the model manned mission to Mars has been established.

There is architecture among other branches of science and engineering connected with manned missions to Mars, but not yet contributing much. There is not much literature on the subject of a shape and a construction of the future base on the Red Planet. There are mostly sketches of some solutions, in some other suggestions there is one particular technological solution described in details. There is still not enough professional literature showing clearly and technically guidelines and possibilities of the architecture on Mars, as well as there is nowhere to find such literature concerning an architectural design of Mars colonization. A phrase “an outer-space architecture” is rather thought as a non-science concept. On the contrary, the actuality of the problem of building settlements in the Universe shapes the whole new definition of the phrase. The author thinks that science work in these realms may trig a better understanding of a turning point age humanity lives in now; it may also induce some to join the researches, which are focused on finding successive final solutions to overcome the restrictions keeping us from the colonization of the Universe.

It is difficult to decide for now what would be the possible course of the colonization of Mars. There might be implemented a division for four significant stages:

I first manned missions should exploit small habitat modules, for a few people only;

II settling a Martian base consisting of several, connected together, small modules, or one larger module intended for occupation for several and even for several dozen people;

III building a Martian base, and it should be at least one larger building for a constant, or long term, occupation for several dozen and even for about a hundred people;

IV gradual expanding of the base (other objects) to the urbanization level, with the occupants above a number of a hundred.

Although the firs stage, accepted in the NASA plan, is probably unavoidable, at the same time it is the most difficult one, due to the psychological stamina of the crew of such manned missions. That is why the author here is confident that the first lodgings there should be built as a comfortable base.

1.2 Assumptions directing the researches

1.2.1 The basis to star researches

The basis to begin researches, conducted by the author in the subject of architectonic problems for Martian base as a habitat are: program Mars Direct, two basic questions about Martian base, and the current speculations in the subject of architecture of Martian base.

Program Mars Direct has been worked out by the USA scientists (Zubrin and Wagner 1997), and partially adapted by NASA to create schemes of human exploration of the Universe, widely known as Mars Design Reference Mission. The problem of architecture of Martian base is one of its elements. Mars Society scientists and its members working in different fields of science all over the world, are constantly working on the program, and expanding it constantly. The author, as an architect and a member of Mars Society Poland, works on the architecture of Martian base, considering this as an element of the research connected with the human exploration of the Universe.

Two basic questions about Martian base: There are two questions constantly propound among subjects of concern about Mars settlement. The first one concerns technological problems connected with an accomplishment of such a construction that should facilitate safety for people in extreme Martian conditions. The second one concerns socio-psychological problems connected with the human psychological stamina in an enclosed environment, in extreme conditions. Both the questions might be examined in a matter of architecture; the first one concerning the problem of construction, and the second one concerning the problem of its form, functions and interiors. It is possible to take into consideration both of the problems only after having analyzed conditions on Mars and its environment as a specific place to live. The two problems have concurred to the subject of this dissertation: The Architectural Problems of Martian Base as a Habitat in Extreme Conditions.

The two basic questions have been defined, focusing the author's consideration on the architecture of Martian base:

1. *How to establish a safe shelter for people in Mars conditions that would enable them for a long-term stay on the planet?*
2. *How to establish a human-friendly habitat on a strange and distant planet?*

The current consideration of the architecture of Martian base: The beginning of the serious consideration of the architecture of Martian base is crucial nowadays; the arguments below explain why:

1. First manned missions to Mars would last about 2,5 years. DRM assumes that people should stay in one cylindrical module, 8 m x 8 m, back and forth (summing up to one year); they would spend about a 1,5 year on the surface of the planet in two similar modules, connected together with a flexible airlock. So far any sociological and psychological researches conducted on people confined to unfriendly limited environment (so-called *ICE—Isolated and Confined Environment)* are at the least alarming. Long-term confining to such conditions is a strenuous experience for people psychologically, as well as interpersonally. The natural desire, typical to most of people, is to stay in a larger environment, and to be able to keep in touch with more then few, or a few, human beings. A serious restriction of diversified psychologically positive stimulus may affect irreversibly people, even psychiatrically. Scientists, who study behavior of small groups of people, who stay long in limited areas in extreme conditions, alarm that on the socio-psychological side any manned mission to Mars by NASA may become a complete failure. However, there are diverse methods to limit the negative effect, where some architectonic help may seem important. The sooner a larger habitat would be assembled on Mars, meeting the socio-psychological needs, the easier would be to avoid some possible arduous psychologically situations in life of people on this planet.
2. The subject of Martian architecture is complicated and difficult. It is worth analyzing in advance, before it becomes a factual problem. The analyses of any possible factors affecting Martian architecture, and a thorough search for construction and material solutions, which would be adaptable in local conditions, may become a base to future consideration, as a textbook and study material for our descendants. Essential requirement indicators about constructions and building materials, functional elements and ideas about a shape of Martian base, may stay valid for a long time, and become an inspiration for future designers, similar to Ciolkowski's[1] ideas and Potocnik's[2] guideline projects of orbital bases: they were invented over a hundred years ago.
3. The first manned missions are anticipated in the present half of the age (Tab. 1.1). There is still some time to prearrange to meet this opportunity. Along with the first Marsonauts, there would travel robots or building machines; sending those robots and machines in advance to the planet would quicken the building of the base, and the moment people are actually ready for this challenge.

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1 The first designer of an orbital habitat, on the basis of their engineering ideas have modeled succeeding concepts.

2 Herman Potocnik, alias Noordung, wrote in 1928 a book titled “The Problem of the Space Travel”, where he formulated *inter alia* some guidelines for the architecture of an orbital base including: types of necessary rooms, an optimal shape of the construction, etc. On the grounds of his guidelines, not only projects of orbital base have been constructed, but new architectural concepts of hotels in the outer-space as well, for example the one described in section 6.5 The Space Island Project.

4. The first spaceships for people traveled to the orbit of Earth some time ago, despite of technical limitations, which are no longer such a problem nowadays; this might be analogical to the Space bases, which are due to be improved in a very similar process, and here—on the architectural side. The sooner the problem of Martian architecture is taken into consideration, the more different directing guidelines of technological development might be indicated, especially in the matter of construction materials, insulation and technological connections. Those improvements should influence positively safety, stability and reliability of such constructed structures, and what follows is the sense of safety for future habitants of the Red Planet. Simulations of such structures on Earth, in similar to Martian conditions, might be a real asset to the researches, because the chance of succeeding might be checked. There is still some time for required alterations and adjustments, or even to give up on the building methods which failed during the researches, and which could have seemed as the best ones years ago. Thus, it is crucial now to establish guidelines for Martian architecture, and the survey on different building technologies that are well suited to serve the purpose.
5. So far, there have been no buildings constructed on Mars, and there in no assurance that one technological process is better than another, and that scientists should limit performing researches to one of them in particular. Survey on different solutions should help to state advantages and disadvantages of many of them. One negative aspect, among many positive ones, should not determinate the usefulness of a solution. This negative aspect might be the crucial one to exclude a construction from those that are possible to be built in Martian harsh conditions. However, showing this one crucial aspect might be a starting point for more future researches to overcome the problem. What seems to be impossible and improbable contemporary, in future may become a simple reality, thanks to science and new technologies. That is why specific and detailed analyses might help in future problems with Martian architecture.

1.2.2 The unknown

The author notices the problem of the unknown in connection with Martian base, which may become clear later. There are the main reasons of a reluctant beginning of Martian architecture. In the meantime, as the author states, those are not the obstacles, which should stop the development of researches concerning this problem. They should rather influence the final stage of the programmed designing process of Martian base. A choice of a construction process and a method of arrangement of interiors might be taken into consideration without clearing up the questions stated below:

Functions in the base and the number of occupants: What functions might be needed in the base and in what percentage, and what share of the space they should be granted, is very hard to predict now. Some general view might be stated on the basis of:

- the functions scheme of the outer-space bases,
- the functions scheme of a habitable house,
- the functions scheme of a town.

The above assumptions are based on the status of Martian base: an outer-space base or a colony:

- an outer-space base: a house connected with a workshop,
- a base: mini-town (not a rural area, it should own a high-level infrastructure),
- an outer-space colony: elaborated unit of settlements, an outer-space town (a considerably expanded outer-space base, or a net of bases).

A number of habitants should depend on what imperative of functions it would be restricted to, e.g.: industrial, science researches, tourism or colonization.

Investigating of the functions and urbanization seems to have not much sense because of those two, temporary unsolved, problems. There might be dozens of different scenarios, thus any analyses are problematic, e.g. in a science and researches base one or two kitchens would be enough, with messes adjacent to laboratories; in an industrial base separate canteens (messes) should be indicated, and in a scenario with lots of different functions, or colonization shown as a main factor, several houses with small kitchens, or a developed system of catering should be indicated.

The best building technology: It is very difficult today to indicate which building technology should be put into practice on Mars. Nowadays it is possible only to conduct several analyses of some different technologies, those that seem probable to be adapted in Martian base conditions. Such speculations might help to show advantages and disadvantages of construction processes and materials used there. On the basis of such speculations there might be stated which of them are worth of future analyses and development, to match the requirements of Martian base engineering.

The appearance of the base: It is difficult to state precisely now any appearance of the base: its shape, colors, details, interiors. This is the result of the unknown choices stated above. Nevertheless, taking into consideration different architectonic models, such a question “How is it going to look like?” might be easier to answer.

2 The objectives, research methods and the thesis of the dissertation

2.1 The objectives of the dissertation

To elaborate comprehensively the range of the subject of the dissertation the author stated the following objectives:

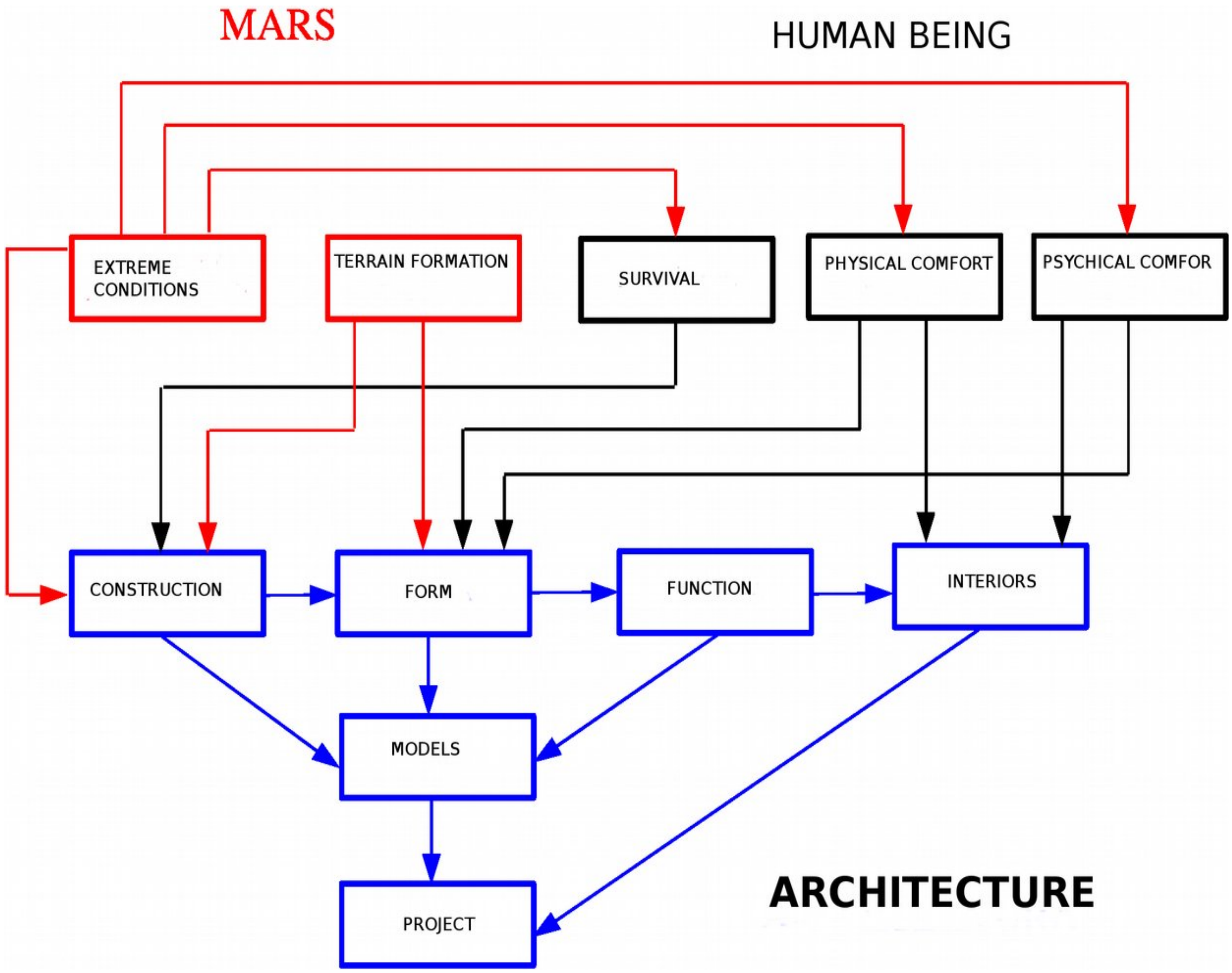
1. The identification of Martian environment as a building site and its influence on the architecture.
2. The recognition of an influence of a human factor on the shaping of Martian architecture.
3. The identification of architectonic concepts that have been established so far for habitats in extreme conditions.
4. A search through, and an overview, of building technologies in view of their suitability for Martian base construction.
5. The identification of different architectonic solutions that would influence the psychological and physical comfort of the habitants of Martian base.
6. Establishing guidelines for an architect of Martian base.
7. Elaborating some architectonic models of Martian base, according to the guidelines, and a detailed presentation of one selected model.

2.2 The manner of conducting researches

Architecture is a specific science domain. It depends on a graphic and a model device. What usually is described in words, is graphically illustrated here. An architecture design is always completed with a technical description, but most of the problems are illustrated in pictures. There will be created a set of architectonic models on the basis of synthesis, and next—one of them will be elaborated and shown graphically. A concept project should be a device to present solutions to prove the accurateness of the thesis of this dissertation. To design such a project, required on the side of the author inquiries of different science domains[1], and chosen to filter in one particular domain—architecture. There are three topic sets

1 Besides architecture there are also: astronomy, astronautics, socio-psychology, geology, mining industry, building materials science.

defined on the basis of different problems connected with designing and building a base on the Red Planet: Mars, Human Being, Architecture. The order of conducting researches emerged out of the connections among the elements of those sets (Pict. 2.1): a cognition of Mars and human relations in regard to the environment there, a possibility of their survival there, and their feeling of psychical and physical discomfort. Knowledge of Mars and human relations in regard to the environment there allows researches strictly connected with the architecture to begin. A uniqueness of the conditions and a harshness of the terrain of the Red Planet significantly restrict any independence of the architectonic designing in the range of its construction. It is proved with the researches of the realizations and concepts of habitats in the extreme conditions on Earth, and in the outer-space.



Picture 2.1: The system of connections of elements among three topic sets: Mars, Human Being, Architecture.

After having analyzed available building technologies, and having in mind the shape of the terrain, it is possible to decide what possible forms of a base are available for the architect. The shaping of it should be restricted to the range of human limitations and to their needs. A functional vicinity of the component modules seems to depend mostly on the form, which is strongly influenced with the availability of accessible building technologies. However, it might determinate a vicinity and connection of base elements, e.g. in a case of some additive architecture. Interiors are considered as an intrinsic element of architecture, which in case of designing Martian base should be treated with particular carefulness, as this is the decisive part for a possibility of enhancing the psychical and physical comfort of habitants. The analysis of construction, form and functions allows creating architectonic models of the base. One of them would be elaborated in details after taking into consideration additional guidelines to design interiors.

The order of conducting researches have been restrained to the methodology of the architectonic designing. First, the building site have been recognized. In this case the observation on the spot is especially atypical, because the building site is located on Mars. The extreme conditions on the planet, and the shape of the terrain have been strictly analyzed in the view of their influence on the architecture. They are elaborated here, in this dissertation in the part “Mars”.

The next step concentrated on the user of those constructions, and what follows —the next atypical situation emerged: there is no way to know exactly who will be going to go to Mars. However, the analysis of typical human needs, and human behavior in such a case, when the fulfilling of their needs is strongly restricted, should help to define several requirements of a user, regarding Martian base. This problem is elaborated in the part “Humans”.

Due to the specific example of architecture of Martian base, the analysis of habitats in extreme conditions on Earth and in the outer-space is conducted. This way, the recognition of available architectonic solutions in difficult environment is provided. Thanks to the research it has been possible to define which are worth copying.

The next thing the author has done here is the recognition of all the elements of the Vitruvius Triada of architecture: Construction, Form and Function, completed with interior design. The chosen order depends on the manner of systematics of conducted researches, Pict.2.1. There have been analyzed only those technological solutions, which the author recognized as being useful on Mars. There have been identified possible solutions for the form of the base, and what is more, there have been imposed several restrictions to those. Taking into consideration the outer-space architectonic concepts in literature allows the author to conduct a critique analysis of those concepts and choose inspirational ones to imitate.

Only then, on the basis of conclusions for architect which are collected in following sections the author has been able to create several models of base which would be possible to build in Martian environment, and which are directed to fulfill its users' needs in a satisfactory manner. One of the models has been elaborated here, its interiors and some details too.

2.3 Research methods

The methods of conducting researches and objectives of the dissertation defined by the author influenced the collection of methods, which are figured out below:

1. The analysis of Mars as a building site, and the synthesis of possible environmental factors that could influence the architecture of Martian base, on the basis of data concerning extreme conditions on Mars, collected with the exploration probes and elaborated in different science works.
2. The analysis of habitats of people living in isolation, in small groups, in extreme conditions, in relation to the habitat's architecture, on the basis of socio-psychological researches.
3. The overview analysis of habitats in the extreme conditions on Earth and in the outer-space, to recognize methods of habitable constructions verified so far in such conditions.
4. The critique analysis of outer-space habitat concepts in literature as an inspiration for a designer of Martian base.
5. The detailed analysis of contemporary known building technologies, which seem promising to be available to adapt to the extreme conditions on Mars.
6. The analysis of architectonic concepts carrying the strongest influence to create psychical and psychical comfort.

2.4 The thesis of the dissertation

The main thesis of the dissertation is to demonstrate that:

Contemporary technologies along with the science and knowledge level about the extreme Martian conditions allow people to design and build a Martian base as a human-friendly habitat.

As a part of stated above, there have been stated following partial theses:

1. Extreme Martian conditions need specific architectural designing.
2. During the process of defining architectonic problems on Mars, the main factor are socio-psychological reasons.
3. With the help of architectural tools there is a possibility to improve the psychical and physical comfort of habitants of an outer-space base, and to create a human-friendly habitat on Mars.

3 Mars

3.1 Mars Conditions

Gravitation

Mars in diameter is two to one in comparison to Earth: it is 6794 km. It is also ten times lighter in comparison to Earth, and its average density is 3.9 g/cm^3. Because of that the gravitation on Mars is only 3.69 m/s^2, so approximately 1/3 g (ESA 2007).

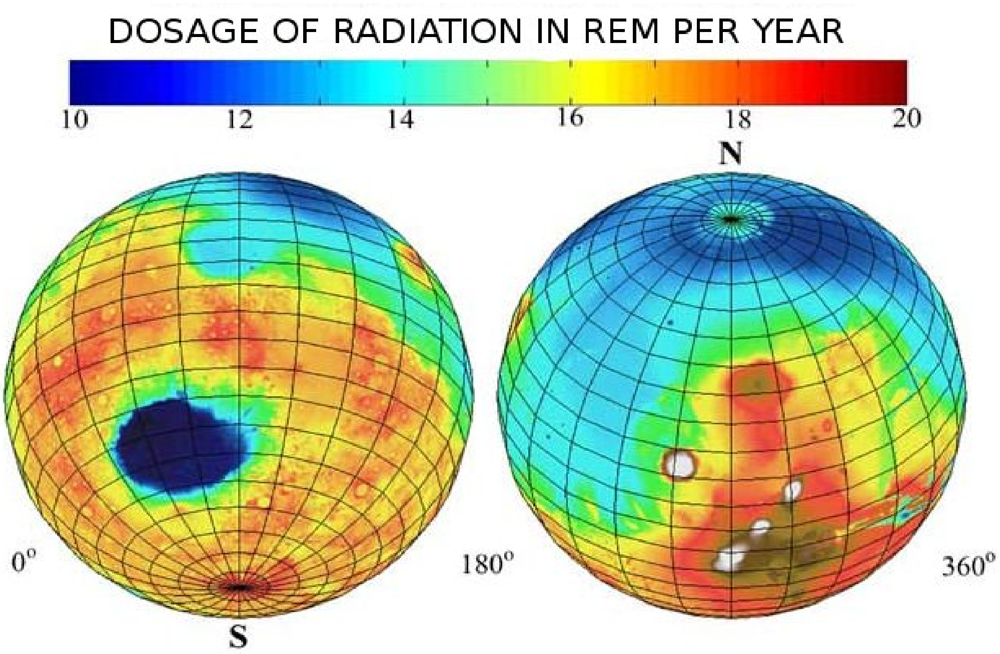
The influence of gravitation on the architecture

1. A carrying capacity and durability of the construction must be counted in regard to a lower gravitation. Thanks to small acceleration on Mars, there might be built more massive buildings than on Earth, even on more tenuous grounds.
2. Lower gravitation influence the way people move around. It is highly recommended that there should be applied ergonomics different from those applied on Earth.
3. Lower gravitation conditions limit significantly the use of mussels. To keep them fit and strong to come back safely to Earth, there should be anticipated a place to exercise on the base.

Radiation

Because of the low density of Martian atmosphere a significantly larger amount of every type of radiation can reach a surface of the planet, much more then it takes place on Earth. There are two main sources of harmful for a human being radiation: the Sun and the Space radiation.

The solar radiation might be of different character, and it demonstrates itself with: visible light radiation in the visible spectrum, ultraviolet radiation, and highly energetic solar radiation. The distance from the Sun to Mars is one and a half to one longer than to Earth, so less then a half of solar visible light reaches Martian orbit, in comparison to Earth (the solar constant on Mars in regard to the Earth's = 0.43) (URANOS 2005, ASEB 2002). Because of the small density of Martian atmosphere clouds are rare there, and most of the solar light reaches the planet. On Earth, with its thick and dense gas shield, which is rich in water vapor clouds reflecting strongly the white light, a smaller fraction of radiation reaching the orbit can reach the surface of Earth (Mieszkowski 1975). On Mars clouds (especially those which are made from water vapor) are rare, but there is a light, slight dust in the atmosphere which limits effectively the amount of the light that reaches the surface. The stronger winds, the more dust particles remain above the surface. During a strong dust storm on the surface of Mars, the area is left in darkness. Some of the storms may last even for months, what results in low amount of visible light during that time.



Picture 3.1: The dosage of cosmic radiation reaching the surface of Earth in according to the geographical location (NASA 2002), per year, given in REM.

In Martian atmosphere there is no ozone layer which could stop ultraviolet radiation. Although its intensity is lower in the distance of 1,5 AU from the Sun than it is on Earth (adequately—1 AU), but because of the lack of ozone in Martian atmosphere, a very strong UV radiation reaches the surface of the planet, which is hazardous for people.

The most dangerous radiation is solar radiation. It is created by a stream of highly charged particles, mostly protons and alpha particles, which moves with enormous speed from the Sun to the external surface of our Solar System (PWN 2006). Even a short time exposure to its operation might be fatal, or cause a strong case of radiation sickness. A human being is not prepared in any way to get such huge amounts of highly energetic radiation (Musser and Alpert 2000). Fortunately, waves of such radiation reach Mars rarely, and they are not so intense each time. The most intense waves of this radiation are strictly connected with solar flares, and as having been under astronomers observation for many a year, they are now more predictable. Their intensity is getting higher and lower in the eleven-year cycle.

Solar flares are almost at once detected by ground-based instruments, telescopes, and before the wave of radiation reaches the surface of Earth, or the surface of Mars, there is enough time to prepare for it.

A cosmic (the Space) radiation, similar to the solar radiation, consists of highly energized ions. Its intensity is much lower (PWN 2006). However, it is still very dangerous, because it constantly bombards the surface of Mars. The Space radiation is not as precisely directed as the solar one is, because it originates from all the stars in Our Galaxy. The dosage rate is expressed in rem. Humans on Earth are being radiated with it only with a fraction of rem per year. During one solar flare (one time event) about 10 rem of radiation may reach Mars. A similar dosage of cosmic radiation is observed after a yearly exposure there (Badhwar 2003). However, such a dosage is dangerous for people, and it is concerned as a cause of cancer, the same as smoking is (Mars Society 2003).

Highly energetic particles damage chemical structures at the impact. When it is a case of organic structures, such as human body structures, it can cause cancer or genetic mutations. The ions can break atomic nucleus of heavy elements, and cause cascades radiation reactions, e.g. in minerals or construction materials, which are rich in atoms of heavy metals. Solar radiation and cosmic radiation is dangerous for people, devices in a base, and constructions of a base.

Radiation on Mars depends somehow on the level above the sea: the higher a ground level is, the thinner the protective layer is, and the higher the intensity of radiation. Places the most exposed to radiation are the mountains. Picture 3.1 shows maps of a yearly dosage of cosmic radiation that can reach the surface of Earth (NASA 2002).

Radiation influence on the architectural designing

1. The amount of visible light that reach the surface of Mars is limited due to the large distance from the Sun. To achieve as much psychical comfort of habitants as it is possible, the biggest practicable transparent partitions are strongly recommended.
2. Construction of the base should be designed to block UV radiation and to limit its reachable amount into the habitat.
3. In regard to constant cosmic radiation amount on Mars, harmful for humans, it is highly recommended to use protective barriers inside partitions of habitats. Because it is not as harmful as the solar radiation, they are not required for every part of interiors.
4. Solar radiation is fatal, so people should have safe shelters. Solar flares, which are the source of it, happen from time to time, so it is enough to build the purpose-objected shelters capable of providing enough room for every habitant of the base, ensuring safe living conditions during dangerous time of solar flares. However, it is preferred that all parts of the habitat should protected against harmful solar radiation. Protective barriers might be installed permanently, or temporary and easy to unfold.

5. Highly energetic radiation may cause cascade radioactive reactions, and thus, construction materials should be made from light elements, such as hydrogen, oxygen or carbon (light isotopes). There might be build some external protective shields, made from materials that can limit radiation dosage as well, e.g. water.
6. Selection of the building site should be preceded with the examination of maps of dosage radiation reaching the surface of Mars, to lower the influence of cosmic radiation with a choice of the safest possible localization for the habitat.

Picture 3.2: The dust partitions in Martian atmosphere color the sky pinkish (NASA).

Pressure and components of the atmosphere

Martian atmosphere mainly consist of carbon dioxide, and there is a low oxygen concentration. Nitrogen is the most common element in the Earth's atmosphere, but its percentage is low in Martian atmosphere. Moroz (1998) gives the composition of Martian atmosphere: 95.72% CO_2, 2.7% N_2, 1.6% Ar, 0.2% O_2. Tiny and light Martian dust can stay in the atmosphere even with a help of a very light breeze. It makes the colors the atmosphere pinkish (Pict. 3.2) (Williams 2006).

Despite of unbreathable Martian atmosphere, because of its composition, it is important to notice that it is not as toxic as it is on Venus (high concentration of sulfur), or so dangerous as on Titan (methane, that creates its gas layer, explodes rapidly in contact with oxygen). On the Moon, the atmosphere creates only a very thin surface-near layer.

Martian atmosphere is very thin. On the surface, its average density is 0.000015 g/cm^3 and it decreases exponentially along with the height (Lei and others 2004). The closer to the equator, the higher density of the atmosphere. Low density influences also a very low atmospheric pressure. The average pressure is 6.5 h Pa (NASA Mars Fact File), and it is less than 1/100 of the Earth's pressure (the average is 1013 h Pa). Due to the low pressure, Martian atmosphere reacts rapidly for any energy bust, i.e. any changes in temperature; winds are easy to generate, and it can lead to pressure fluctuations (MGCMG 2006). Daily incalescence and nightly temperature reduction in the atmosphere can cause cyclical carbon dioxide sublimation and condensation processes. Carbon dioxide in state of gas drifts up and mixes with the atmosphere causing its higher density and higher pressure. The warmer day, the more carbon dioxide sublimates, and the higher the pressure is. v

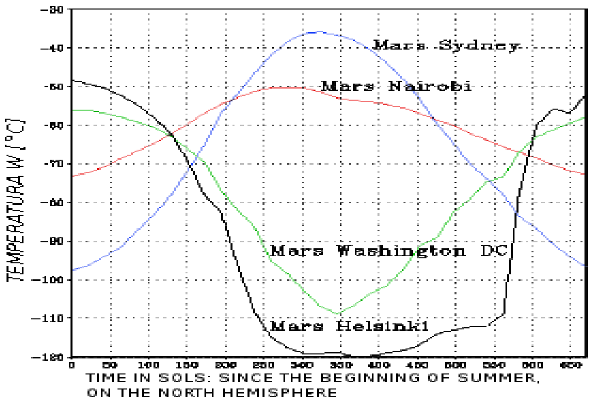
Density, pressure and composition of the atmosphere as influential factors on architecture

1. Martian atmosphere is not suitable for people to breathe, so habitats must be hermetic, and artificial atmosphere must be sustained, in terms of suitable components and pressure.
2. Due to large difference between outside pressure to the one inside, essential to live, the walls of habitat must be hermetic, airtight and tensile resistant.
3. Assuming that characteristics of the composition of gas inside the habitat should be of higher pressure, fluctuations of atmospheric pressure outside are too small to affect the tension changes in the construction.
4. The pressure on Mars is too low for plants to take water from the ground. At the same time, water there occurs in a state of gas and liquid there. Considering this, agriculture should be placed inside especially hermetic and strong constructions, where there could be higher pressure maintained.
5. In cases of above-surface constructions, moves of Martian mass of air should be analyzed. Constructions of considerable height may block the flow of atmosphere and cause cumulations of denser air on one side, what would cause a permanent state of low pressure on one side, and high pressure on the other side. Such a phenomenon may cause faster fatigue loads of construction material.

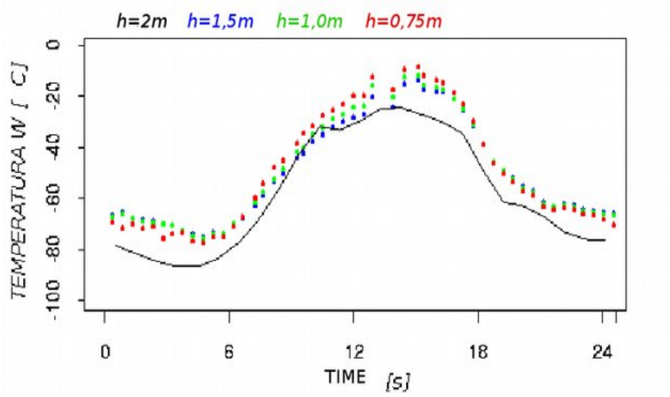
Temperature

The average Martian temperature is only minus 60 ^{O}C. Yearly fluctuations near the surface of the planet are large: during the coldest winter nigh the temperature can drop to minus 140^{O}C, and during the warmest summer day the temperature can rise to plus 27^{O}C (ESA 2007). Because Mars goes round the Sun more elliptic than Earth, one of the hemispheres, the south one, becomes warmer in the summer season, and as it gets considerably less heat during winter season, it becomes colder during that time. That is why the most significant temperature differences are to find on the south hemisphere. By contrast, the little temperature differences are observed on the equator, where charts of yearly temperatures fluctuations similar to the ones in Earth cities (on similar latitudes) are shown in the Picture 3.3. It can be observed that the closer to the equator, the more stable temperatures are. Charts of yearly fluctuations for similarly placed cities on Earth are shown in the Picture 3.3. It is seen that on latitudes closer to the equator (Mars Nairobi) during the whole year the temperature does not drop below minus 80^{O}C. The farther from the equator, the colder temperatures are noted. At the same time it is observed that in many places temperatures never rises to the point of water sublimation.

Additional to meaningful yearly temperature fluctuations, there are 24 hours changes in temperature. The surface of the planet gets warmer starting at dawn and gets cold fast at night, because thin atmosphere does not block free flow of the heat. Human beings are not adjusted to live in such rapid temperature changing environment. It should be noted that there is no other planet in our Solar System that is characterized by more advantageous temperatures; Venus and Mercury are extremely hot, Jupiter and other planets are extremely cold. The Moon is characterized by temperature slightly above the absolute zero (approximately minus 270^{O}C), the same as it is in the Space.



Picture 3.3: A chart of yearly changes of Martian temperature on latitudes similar for cities on Earth: Washington, Helsinki, Nairobi and Sydney (Mars GCM Group)



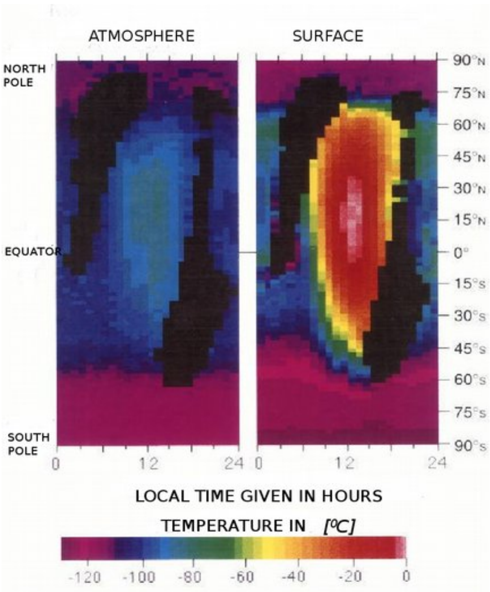
Picture 3.4: Temperature on different heights above the ground measured by Pathfinder (Tillman 1998b)

During the warmest day the temperature can rise up to plus 27^{O}C, but the surface gets cold rapidly. Exceptionally thin Martian atmosphere is not on any account a barrier able to keep the heat that the ground gives back. The temperature rapidly drops down the higher the measurements are done: during the day people could feel colder at the height of their heads than in their feet, and conversely at night. Only around 6a. m. And 6p. m. temperatures become more or less even. This is proved by the measurements made by Pathfinder sensors on levels: 0.75 m, 1m and 1,5m above the ground, what is shown in the Picture 3.4 (Tillman 1998b). Martian atmosphere is very thin, so the greenhouse effect caused by carbon dioxide there is almost none. The heat gets into atmosphere fast and gets out of it as well. Because of it the ground in not able to keep the heat accrued during the day. On Earth, a stable yearly temperature can be often found in the ground on the depth level of several meters only. In Martian atmospheric temperature conditions it is not possible.

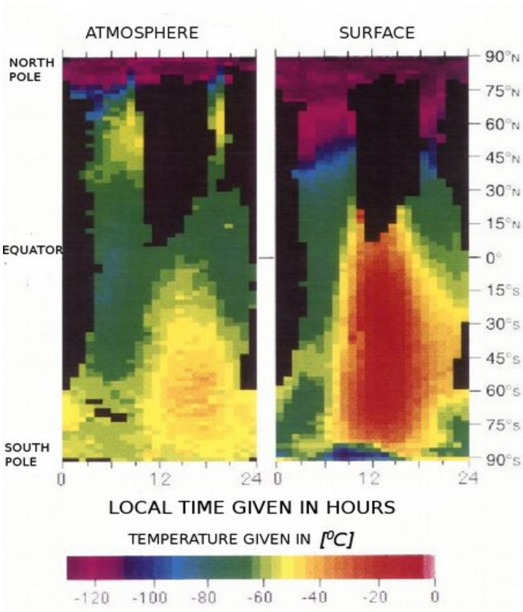
The average temperature amplitude for 24 hours on Mars is about 40 centigrades, but it can rise up and above 60 centigrades (Pict. 3.5). The date comes from researches done by Viking and Pathfinder. During dust storms the difference between the maximum and the minimum temperature during the 24 hours gets significantly lower–to a dozen or so centigrades. During a day the temperature could be lower, even around 20 centigrades, and at night it is usually warmer (Pict. 3.6).

The dust layer blocks a large quantity of the sunlight and at the same time it stops the ground from losing its heat. After a dust storm, when dust settles down, the temperature comes back to its average value for dozens of sols.

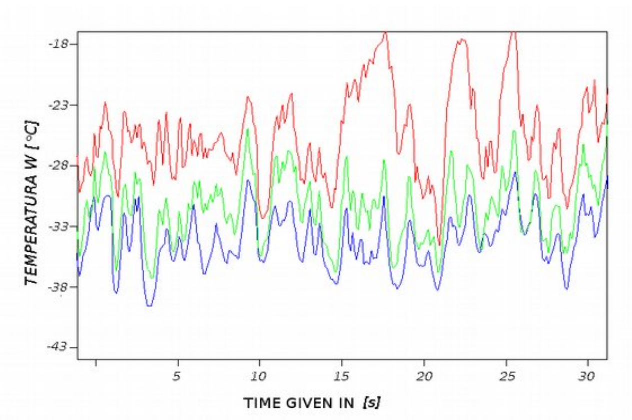
There are also momentary fluctuations of the temperature on Mars that become sometimes very drastic. During 8 seconds their amplitude can reach even a value of 20°C. The graph in Picture 3.7 shows the changes noted by Pathfinder during 30 seconds. The intensity of those changes depends on the weather during collecting data and on the time of the day. There are changes noted by Pathfinder during two days in Pict. 3.8. At night they are significantly smaller (Schofield and others 1997).



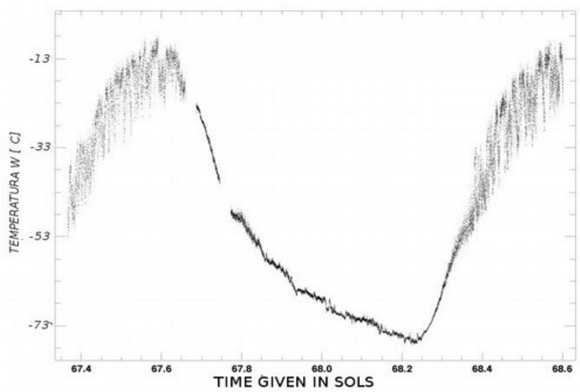
Picture 3.5: The graph of yearly temperature fluctuations on latitudes responding cities on Earth: Washington, Helsinki, Nairobi and Sidney (Mars GCM Group)



Picture 3.6: Temperature fluctuations in 24 hours with large cloudiness (University Chicago Laboratory Schools)



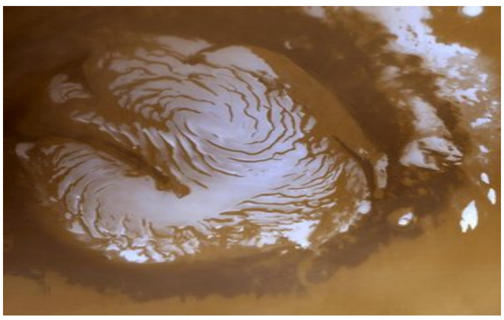
Picture 3.7: Rapid changes of temperature during a day in seconds (Tillman)



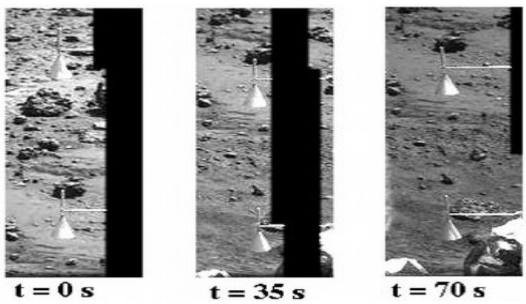
Picture 3.8: Changes of temperature during 2 sols (NASA/JPL)

The influence of the temperature on the architecture

1. It is crucial to establish habitable building that would protect people from low temperatures, and from their large yearly fluctuations, as well as from seasonal, daily and momentary changes.
2. Construction of a base should hold on against low and changing temperatures.
3. In regard to the most favorable temperatures, the location of a base should be considered in places near the equator, where there is relatively warm during the whole year, and the amplitudes of temperature are small. In the south the temperature can rise up even to 27^{O}C, but in winter there is very cold there. The lowest temperatures are noted near the poles.
4. Extreme temperatures constricts a choice of building materials that might be used for building a base. However, the closer to the equator, the lower temperature drops and what follows, a larger choice of construction materials is available. E.g., on the landing places of Vikings and Pathfinder the temperature has not dropped below minus 100^{O}C, and near the equator it has not dropped below minus 70^{O}C.
5. The temperature on Mars depends on the height above the ground level. On different heights construction would be located in slightly different temperature environment, so it would be under slightly different pressures, and changing in time. Considering this, any inside partitions must be extra resistant, in terms of contractions and fatigue.
6. Because Martian atmosphere is especially thin, it does not absorb heat by convection, so it would deflate heat in small amounts from the inside of the habitat. This is influential for the design of insulation. In rooms, where there would be devices working constantly, and emitting large amount of heat, a problem of over-heating and disposing of it might be faced. It might be crucial to install a special kind of ventilation devices. Planning next to each another rooms of different level of heating up may make it easier to keep the temperature on the even level in the habitat.



Picture 3.9: Clouds over Martian north pole (NASA)



Picture 3.10: The changes of the wind strength depending on the height above the ground (Pathfinder Weather Data 1997)

Winds

Martian atmosphere is very thin. In spite of this, winds occur on the Red Planet, sometimes reaching enormous speed, and strong enough to sweep up the surface dust very high.

The key reason of creating winds on Mars are sublimation and condensation of carbon dioxide (the main element of the atmosphere) that follow the changes in the temperature (Tillman 1998b). The creation of winds depend on the surface shape. There are no water reservoirs on the planet that could stop strong wind blows, as it takes place on Earth. The weather becomes predictable because of small winds' fluctuations. The next consequence of it is that very strong winds may rush enormous distances practically unstoppable, and starting dust storms encompassing even the whole planet. Consequently, this might take several or even more months before such a dust storm settles down (Mars Climate NASA 2006).

The data concerning *inter alia* the global behavior of winds on Mars comes mainly from American orbiters Viking, 2001 Mars Odyssey, and Mars Global Surveyor. Due to the fact that its axial tilt is similar to the Earth's, there is a similar division of tropic zones, moderate zones and pole zones. There are similar to the Earth's trade winds in tropic zones, but in moderate zones the winds are directed more differently with West directed domination. Winds near the poles are shaped spiral, which is very typical for them, and their shape might be recognized from the shape of clouds, which mass drifts above them in summer time, and sublimate huge amounts of carbon dioxide and water (Pict. 3.9).

Picture 3.11: An artistic vision of a dust-whirl on Mars (GSC NASA 2004)

The researches conducted by American spacecrafts Viking and Pathfinder have been analyzed and published in different documents by NASA. They give important information about local demeanor of winds. Pathfinder is equipped with three sensors, attached on different heights above the ground to the vehicle, measuring the direction and strength of winds (Pict. 3.10). Large fluctuations of speed and directions of winds are registered by Pathfinder during its firs sols of its stay on Mars. At night winds blow from the south, at down from the west, in the early hours of afternoon from the north, in the evening—from the east. The morning winds are registered as the strongest ones (50 km/h), the weakest—in the late afternoon (25 km/h). The night winds are probably cold masses of Martian air, coming down the hills of Ares Valley, north side, where Pathfinder landed. Later, the dominating there west winds start, during a day the temperature rises and winds get weaker, in the evening gentle winds start, similar to the one known on Earth. Large fluctuations of direction and speed of winds, which occur repeatedly during several consecutive sols, show that there might occur in one place and during one sol winds of completely different characteristic (Pathfinder Weather Data 1997).

The average speed of Martian winds is 36km/h. They are usually of moderate strength, and their speed do not exceed 100km/h. Only during large dust storms Martian winds can reach the speed of 100 – 160 km/h. Because Martian atmosphere is extraordinary thin, the pressure of even the strongest winds would be felt exceedingly weaker than on Earth.

There are dust-whirls on Mars (Pict. 3.11), so called *dust-devils*, similar to tornadoes on Earth, but of notably smaller scale. Their diameter fluctuate from 10 to 100 m, and their speed from 32 to 96 km/h. They might reach a kilometer up, or even higher. Such dust-whirls are quite common on Mars. The particles of dust whirling in the air-whirl rub one another, get heat and pick up static minus. Smaller particles of dust lift in the upper part of a tornado and pick up static minus, and bigger and heavier ones stay down in it and pick up static plus. They establish a huge kind of a battery generating an electromagnetic field (GSC NASA 2004).

The winds' influence on the architecture

1. Despite its strength, Martian winds are not dangerous even during strong dust storms, because of the very thin atmosphere. Constructions do not need to be very resistant to the wind pressure. However, the designation of direction of the strongest winds on the chosen building site might be helpful for the designing an object of uneven dispersion of weight, e.g. because of more then one floor in some parts of the habitat.
2. Due to the electrostatic picking up of particles of dust drifting in the air, especially during dust storms, the outside layer of the building should be characterized with high electric resistance.
3. The outside layer of the base should be considerably lasting and very smooth, to prevent dust from damaging it and from settling on it. This is especially important in case of transparent partitions and windows, which should be intensely protected from dirt.
4. It is essential to avoid arising or presupposing noises connected with the “rain” of particles during strong winds and dust storms.
5. Because there are variable winds in 24 hrs, construction should be able to

resist their pressure from all of the sides. The denotation of the strongest winds direction could help to determinate the safest disposition of entrances and windows of the base. It should be considered on which side of the construction the largest amount of dust is to be expected. The disposition of the entrance airlocks on the lee side would protect them from settling up large amounts of dust. The same consideration is crucial for entrances of magazines and garages.

6. Winds depend on the latitude and the shape of the ground. Localization of a base in the open flat plane is connected with a high probability of occurrence of particularly strong winds. A danger level of intensive winds penetration is considerably higher on the south hemisphere, because especially there the most dangerous dust storms in spring and summer time should occur.
7. Dust-whirls are quite common on Mars, however there are areas where they occur more often. In regard of the danger for people walking there on the surface of the planet or traveling in vehicles, and for rovers, places of occurrence of Martian mini-tornadoes should be avoided while choosing a building site for the base. Electromagnetic features of those whirls might affect badly different devices in the base, and even destroy them. Only underground bases should be considered in such places, and well isolated from the surface environment.
8. In the areas of strong winds there is much dust in the air. What follows is the darkening of the sky. Only 45% of visible light reaches Mars, in comparison to Earth. That low intensity of light on the surface might be the reason of lower level of psychological comfort of the habitants of the base.
9. While choosing a building site in the area of diversified shape, a lower possibility of predictable weather should be taken into account, because a shape of the surface is crucially influential on the weather there.

Water

There is no liquid water on Mars: it is unsustainable. Under the conditions of pressure and temperature there, water can occur only in a state of gas or ice. Those conditions change only on some underground level.

Water vapor is about 0.13% of the atmosphere, that gives 1-2 km^3 for the whole planet, when at the same time on Earth there is about 13 000 km^3 of it. However, it can still create water clouds, low-level fog or ground hoarfrost. Water vapor holds on lower heights (up to 20 km), than volatile carbon dioxide. Water clouds can be observed mostly in winter mornings (Pict. 3.12). In winter there is cold enough for water to re-sublimate from the atmosphere. When a day gets warmer, it comes back to the atmosphere (Titov 2002).

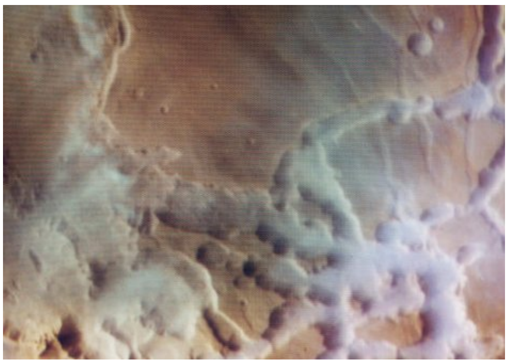
The results of observations conducted with a neutron spectrometer placed in the orbiter Mars Odyssey by the Los Alamos scientists lead to conclusion that there is enough water on Mars to support human exploration. The ground water has been searched even several meters deep into the planet and it seems that there is enough water to cover the whole planet with a 13 cm high layer of water. There might be other layers of water underneath (Ambrosiano and Danneskiold 2005).

There are large amount of ice above 35^{o} north and south latitudes. Up from 55^{o} latitude to the poles, the ground is rich in iced water. Their mass consist about 50% of water. If a kilo of this ground was heated, it would result in gaining a half a kilo of water. Near the equator there are two of similar areas also quite rich in water: its mass in the ground reaches up to 2-10%. The first area is located in Arabian Terra with its center in Crater Schiaparelli. The second one is located on the opposite side of Martian Globe, and its located around and in Locus Planum, and it is twice as small as the first one (Ambrosiano and Danneskiold 2005). These areas are pictured in red on the map in Pict. 3.13.

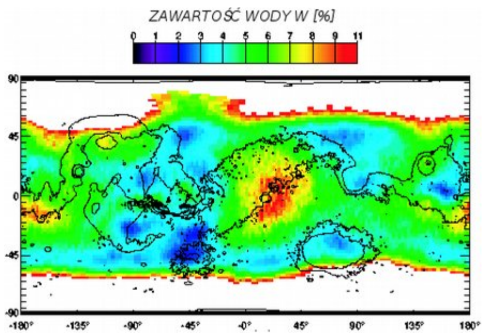
Martian soil is rich in zeolites, aluminum and magnesium sulphate: those are minerals that can contain considerable amounts of water. They have adsorbed hydrogen chemically and have been storing it for millions of years as water. The rocks in the tropic areas most probably had been formed in times of the tilt of 35^{o}, and not 24^{o} like nowadays. That time water could have been freezing on lower latitudes. For now, it is not known how deep the rocks containing water can reach, but the amount of Martian water might be enormous (Ambrosiano and Danneskiold 2005).

The observations of different forms of terrain can lead to conclusion that water streaming down on the surface in the history of the planet is a probable fact. There are nets of smaller and larger channels; grooves in the hills might have been created by ice crystals moving down, and now they are probably formed by ice crystals moving right under the surface, when its temperature rises (NASA 2003a).

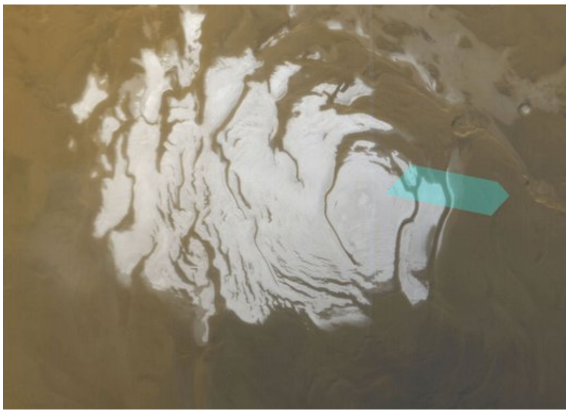
There are thick water and carbon dioxide ice covers on Mars, mainly on the poles, in a form of ice caps (Pict. 3.14), and also in a form of a glacier on bottoms of craters (Pict. 3.15). Ice on Mars is usually firm because of constant low temperatures, especially in the overshadowed places. There are temperatures below zero close to the north pole, that is why ice cover there never disappears, but on the south pole the ice may evaporate almost completely during warm summer.



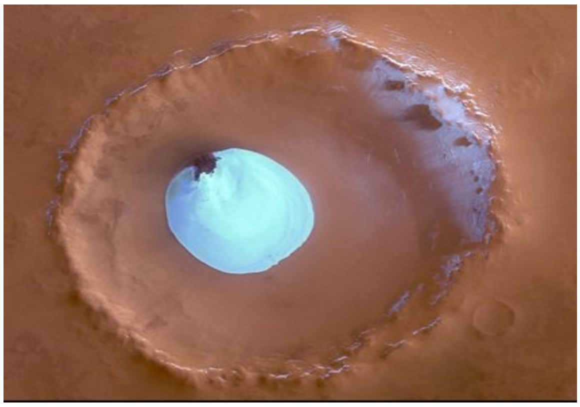
Picture 3.12: Clouds over Noctis Labyrinthus (Viking Orbiter Views of Mars, NASA)



Picture 3.13: The map of water occurrence on Mars (Los Alamos National Laboratory)



Picture 3.14: Ice cap on the south pole (NASA/JPL/MSSS)



Picture 3.15: Ice cap 200m thick covering a Martian crater (ESA)

Water's influence on the architecture

1. There is enough water on Mars to supply it to the base. There should be water tanks planned there.
2. Because water is a crucial factor for surviving, a base should be planned in vicinity of its resources. Its localization is appointed by aquifer: Terra Meridiani and Locus Planum, alternatively close to the poles areas, or overshadowed slopes. There might be other areas taken also into consideration, provided that there would be large amount of underground water discovered on considerably easy to reach depth.
3. Ice might be a suitable building material on Mars in the areas where there are constant temperatures below zero. It might be leveraged from aquifer rocks, ground hoarfrost, or water vapor from the atmosphere.
4. If ice-water would be used as a building material on latitudes where it sublimates during warmer sols, it should be recommended to ensure a tight outside cover on this kind of a building material.

Regolith

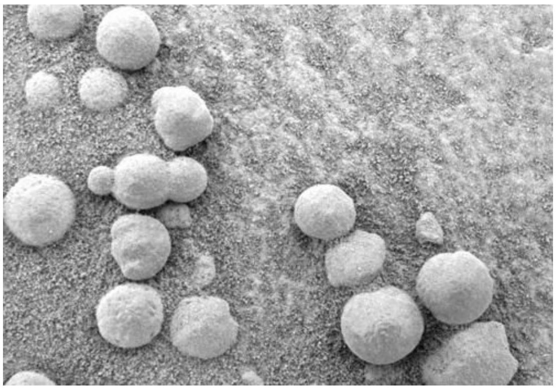
Regolith is an outside layer of lithosphere made by loose surface rocks and ground (ASEB 2002). The surface of Mars is covered with a thick layer of crumbled rock (Pict. 3.16), dust, soil, and other related materials (Nawara 1980). This is the effect of strong weathering, caused by daily large temperature fluctuations, and winds. Taylor says (2002) that most of Mars surface is covered with a very tiny, reddish dust. It settles in depressions, and creates dunes pushed by winds. Its gauge may be large, even over several meters. Those parts of the planet, that are not covered, are usually dark, almost black in color. The researches conducted by Mars Global Surveyor proves that those types of rock are of volcanic origin, which has been confirmed by researches conducted by all the other Martian rovers. Kraft and others say (2002) that there are two types of those rocks, volcanic origin, on Mars: S1 and S2. Type S1 is basalt, very similar in its composition to its Earthly correspondent. The second type—S2 is compared to andesite known on Earth; it is similar to basalt and that is why it is sometimes labeled andesite-basalt. Basalt is the most common rock in our Solar System; it can be found on Venus, Mercury, the Moon, and on some asteroids (Taylor 2002). Basalts are rocks of volcanic origin, they are very fine-grained in structure, and rock solid. After the recasting, they are very hard and and hard-wearing. Andesite is a magma rock of porphyritic structure, gray, darkish, green or black. It it not as hard as basalt is. It is exploited on Earth as a building and decorative material, and also as an acid-proof material. Andesite rocks, however, are easy to weather, creating clay soil, rich in plant nutrients, such as calcium and magnesium.

Basalts and Andesite, along with their rock's rubble, are common on the whole Martian Globe, where basalts are most often to be found in the geologically older south; Andesite are most common for younger north. The absence of mountain corrugating, and lack of any nature (fauna or flora) is the cause for geological homogeneousness on Mars. Non-adjacent slides, which are typical for Martian crust, are the result of basalt rocks breaks, shrinking during congealing (Nawara 1980).

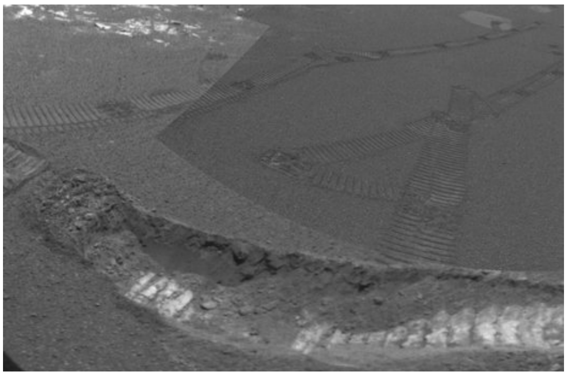
During hydro-volcanic eruptions, where magma interacts with surface or underground water, some specific terrain forms are being shaped, which consists of the rock named tuff (Marti and Ernest 2005). There have been discovered many small terrain shapes of hydro-volcanic origin, similar to Earth's tuff cones (Fagents and others 2002). Layers of tuff may be created by common volcanic eruptions. Tuff is a kind of light, dense, usually porous, sedimentary rock. It consists mainly of sand and volcanic ash, cemented together with silica or silt. Tuff is easily molded, and at the same time it is a long lasting rock.

There are silvery-gray pellets scattered around in some places on Mars. Those are spherical variants of hematite (Pict. 3.17), which is also typical for some Earth deserts (NASA 2004a). Hematite is a mineral, among other iron ores, that might be recast.

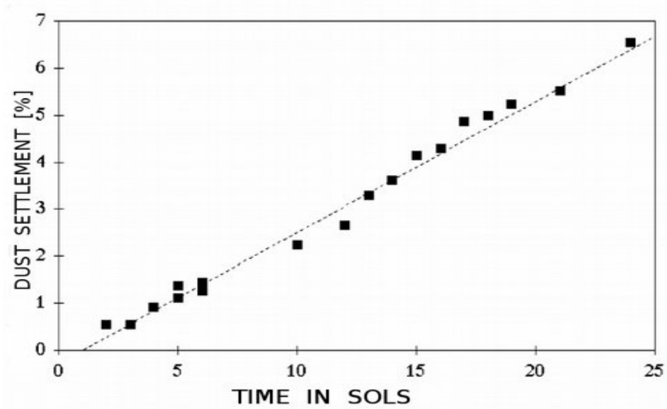
Picture 3.16: A basalt rock Adirondack , a shot taken by Spirita (NASA)



Picture 3.17: Hematite in Martian ground (NASA)



Picture 3.18: *In a glutinous Martian ground clear tracks of a rover have been created (NASA/JPL)*



Picture 3.19: Speed of settling down of dust on solar panels of Sojourner (Landis i Jenkins 1997)

Martian ground is a mixture of very tiny particles of dust and particles in size of sand grains, originating from weathering processes of volcanic rocks. The researches on Martian dust in the atmosphere show that those grains are shaped like flattened tiles, looking like sticky clay, and they are not in identical dimensions, like spheres of river sand are (Markiewicz and others 1999). There are being discovered areas rich in clay layers in the ground. They have been probably created because of water operation (MRO NASA 2006). A viscosity of the ground are best proven with pictures of the tracks left by Martian rovers (Pict. 3.18). According to the new researches it is not yet proven that it contains any organic substance. It bears also no similarity to any kind of soil known on Earth (ASEB 2002). Martian ground consists mainly of silicates, iron oxides, calcium oxides, magnesium oxides, alumina and sulfur dioxide. Similarity of ground composition in landing places both of the Vikings, number 1 and 2, and Pathfinder, too, might mean that the wind operation causes combination and homogeneousness of the whole Mars ground (Morris 1999, Haberle 2000).

Martian dust are tiny particles of the ground, building-up on the surface of the planet, and drifting in the atmosphere. The diameter of the dust in the atmosphere is 1-3 micrometers; maximum to 10 micrometers. The amount of dust in the atmosphere rises during seasonal dust storms, but even during calm season there is enough dust in the atmosphere to color the sky typical pastel-pink tone. It is assumed that dust is the same on the whole planet, because wind moves it evenly. It is characterized by magnetic properties and contains a big amount of iron (JPL NASA 2005). Even during the time when there are no dust storms, winds can push dust on the surface of the planet, covering obstacles with a layer of ground or creating dunes. In case of Sojourner “a mountain” of dust have been building-up on it during every sol by 0.39%. Martian dust is very tiny and able to get into the smallest apertures easily. The average density of Martian ground is approximately 1.2 g/cm3 (Haberle 2000). It contains almost exclusively five elements: oxygen, silica, iron, magnesium and calcium, tied together in form of oxidizes. The approximate mineral composition of Martian ground, according to samples collected by rovers Viking and

Pathfinder is shown by Tab. 3.1, and approximate element composition is shown in Tab. 3.2 (JPL NASA 2005).

Table 3.1: Mineral composition of Martian rocks

mineral	the percentage in a cubic unit of ground
SiO_2 *(silica)*	44,0%
$Fe_2 O_3$ *(hematite)*	17,0%
$Mg O$	9,0%
$Al_2 O_3$	10,0%
CaO	5,5%
SO_3	5,5%
$Na_2 O$	4,0%
TiO_2	1,0%
$K_2 O$	0,7%
MnO	0,5%

Table 3.2: Element composition of Martian rocks

element	the percentage in a cubic unit of ground
O	43,0%
Si	20,6%
Fe	14,0%
Al	5,4%
Mg	5,3%
Ca	3,8%
Na	3,2%
S	2,2%
P	1,2%
Cl	0,6%
K	0,6%
Ti	0,6%
Mn	0,4%
Cr	0,3%
Ni	0,1%

3.2 Land relief

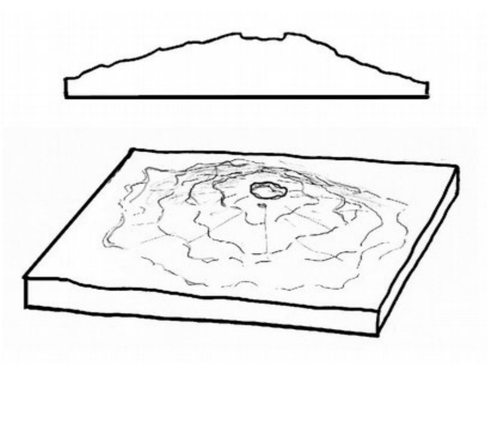
The surface of Mars is approximately equal to the Earth's lands. There are different formations, some similar to those known on Earth. The land relief on Mars is as diversified as it is on Earth. There are no water barriers, seas or river cuts. Martian landscape has been shaping itself for millions of years to become as it is now. The main factors of the process are: operation of winds and water, volcanoes eruptions and meteors drops. Nowadays the surface of Mars does not change much, only winds lift and move dust forming and moving dunes. There is no seismic activity and volcanoes are assumed to be extinct. Most of water evaporated many years ago. The landscape might be considered as a stable one, and there is rather a slight possibility of its changing. On the basis of collected data there are worked out some main types of landscapes on Mars. The author made their profile on the basis of information found on NASA and ESA websites. The following typical terrain formations are shown here in short descriptions, a section and a draft picture of a piece of a land. The documentation is complemented with pictures taken by Martians probes (mainly Mars Express, ESA and Mars Observer, NASA).

Land formations on Mars

Land formations on Mars may be categorized by several main groups: volcanoes, plains, valleys, slopes and craters. Inside those groups there might be listed different types, as it is described below.

Volcanoes: There are three types of volcanoes on Mars: *mons, tholus* and *patera (Caplinger 1994b).* Those are thyroid types of volcanoes[1]. They are distinguished by softly descending slopes, declining in several only percentage of fall (Pict. 3.20 and 3.21). They have been shaped by the lava dribbling slowly from the volcanoes. On the hillsides of thyroid volcanoes there are lava canals, created by air bubbles closed in the dribbling lava (Nawara 1980).

Because of their origins caves are usually located shallow under the ground, but still, it depends on their type. The detailed specification of types of the lava canals shows Frederick (1999). They are usually flattened, that is why they are spacious and their vault is not very high. Daylight can come into the cave through the entrance and by skylights, so-called *hornitos* (Pict. 3.23) (Frederick 1999). The most flattened and at the same time the most spacious are *paterae*. Those are the oldest volcanic formations on Mars. *Montes* are slightly less flattened. Those are the highest mountains of Mars, and at the same time the highest mountains of Solar System. There are several of them on Mars: the best one known is Olympus Mons, 27 km high and 550 km in diameter, and Caldera is 80 km in diameter. *Tholus* is a small thyroid volcano with gentle slopes, a little rounded on the circumference, shaping the hill a little like a flattened dome (Caplinger 1994b).



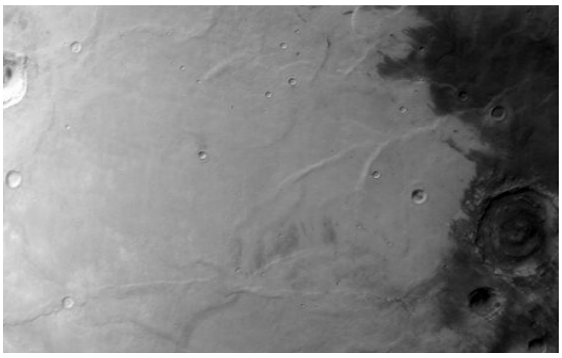
Picture 3.20: Martian volcano: Section, axonometry

Picture 3.21: Olympus Mons – Martian volcano (NASA)

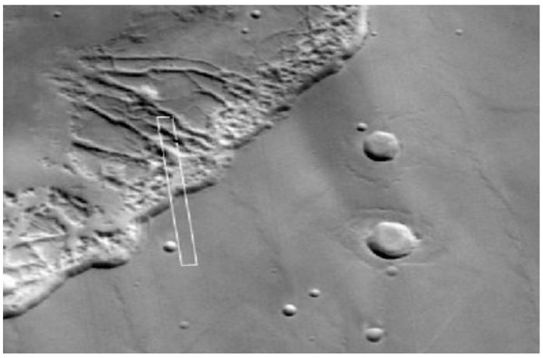
1 Volcano cones typical for Earth have not been observed on Mars.

Picture 3.22: Insides of a lava cave on Earth (Wikipedia 2007)

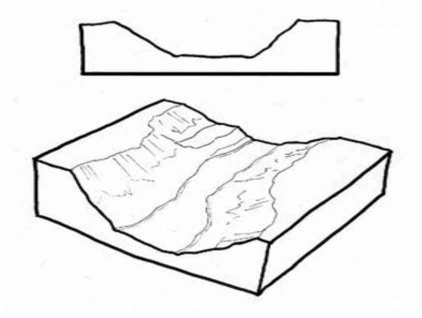
Picture 3.23: Skylights in a lava canal, called ”hornitos” (Frederick 1999)



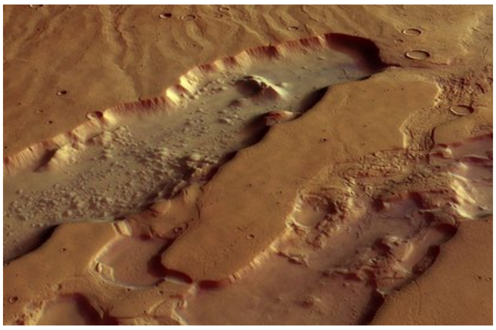
Picture 3.24: Hellas Planitia (NASA)



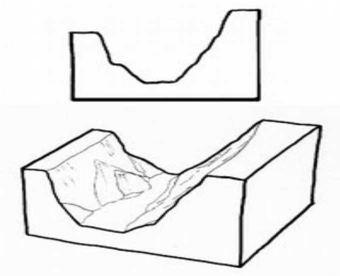
Picture 3.25: Lunae Planum (NASA)



Picture 3.26: Vallis: Section, axonometry

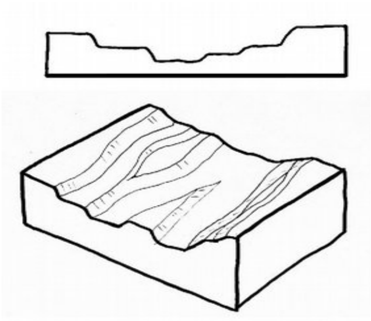


Picture 3.27: Dao and Niger Valles (ESA)

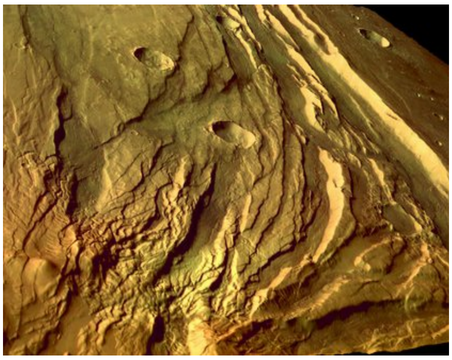


Picture 3.28: Chasma: Section, axonometry

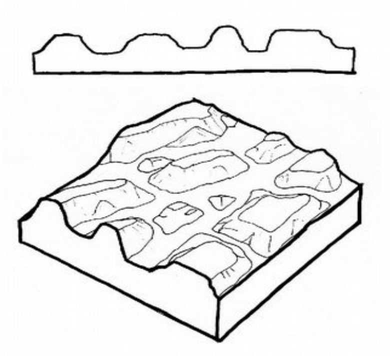
Picture 3.29: Coprates Chasma (ESA)



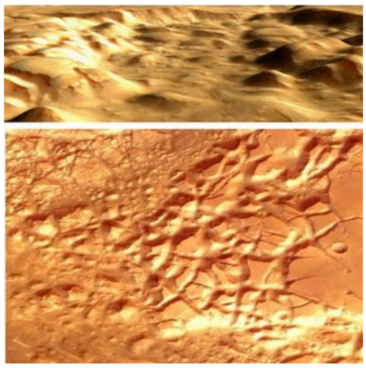
Picture 3.30: Fossa: Section, axonometry



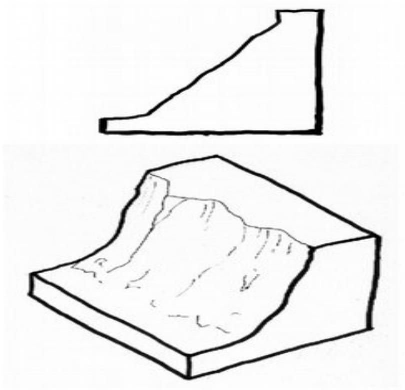
Picture 3.31: Claritas Fossae (ESA)



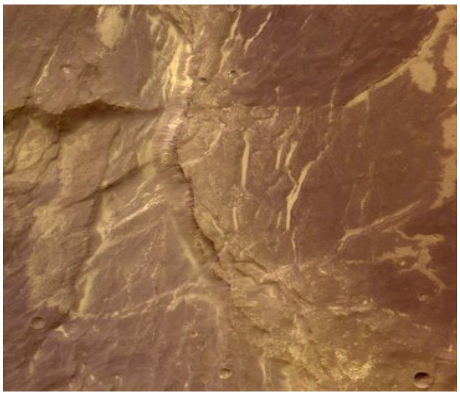
Picture 3.32: Chaos: Section, axonometry



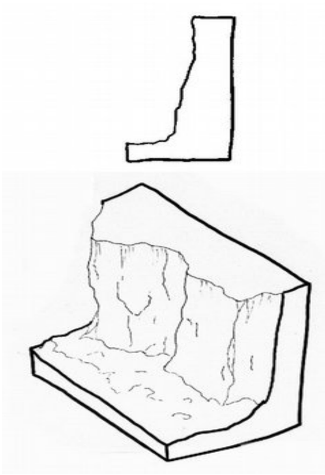
Picture 3.33: Aureum Chaos: perspective of a piece of an area, a view from the orbit (ESA)



Picture 3.34: Rupes: Section, axonometry

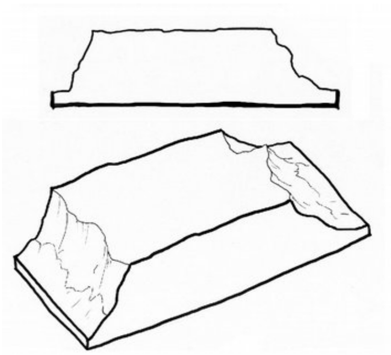


Picture 3.35: Rupes on Claritas Fossae (ESA)

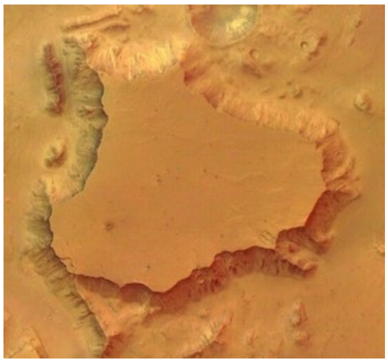


Picture 3.36: Scopulus: Section, axonometry

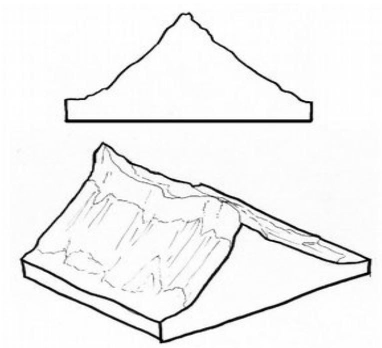
Picture 3.37: Scopulus on Mars (NASA)



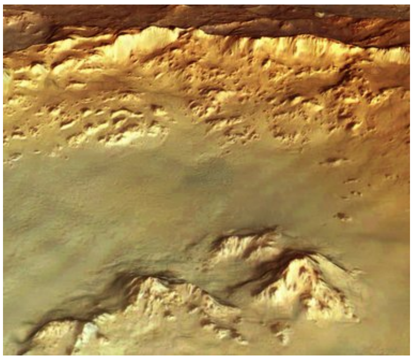
Picture 3.38: Mensa: Section, axonometry



Picture 3.39: Small mensa on Mars (ESA)



Picture 3.40: Hills: Section, axonometry



Picture 3.41: Hills of Crater Hale (ESA)

Plains: Plains on Mars are located on different elevations. Those located low are called *planitia*. Lowlands on Mars are mostly very expansive and vast terrains. They are typical for the north hemisphere and cover most of its part (Pict. 3.25).

Valleys: Valleys are (most probably) the result of water operating there on Mars. They may differ. Martian valleys, which are the most similar to the Earth's river valleys of gentle slopes, are called *valles* (Pict. 3.26, 3.27). The next are *chasmata* and *fossae. Chasma* is a very deep and extended valley with steep slopes, similar to the Earth's canyon (Pict. 3.28, 3.29). *Fossa* is an extended and rather shallow valley. *Chasma* is the deepest type of a valley. It can be found the most often unassisted, and *fossa* lays often in parallel collections of depressions in the ground (Pict. 3.30, 3.31). More complicated, often cross-sectioning systems of valleys divided by hills or ramparts, create *chaos* and *labyrinthus*, e.g. Valles Marineris of depth of 7 km and width of 200 km. Often their bottoms are covered with a thick layer of dust. There might be aeolian landslides found on their slopes. Besides of those, there are lots of smaller valleys on Mars that are not as dangerous as those described above.

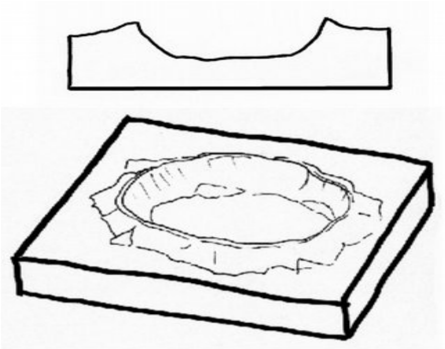
Slopes: Slopes on Mars are divided into two types, depending on their line of the brink of the slope: rupes—an almost vertical ridge, cliff (Pict. 3.34) and scopulus—an escarpment with irregular line of the ridge of the slope (Pict. 3.36 and 3.37). Those sudden and steep depressions in the ground are similar to Earth's tectonic formations. They can stretch ahead for kilometers. They are found single, or close to other land formations (e.g. there are rupes 4 km high around Olympus Mons, Pict.3.21). There are cliffs shown in Picture 3.35 in the Claritas Fossae area. Mensa are flat-ended hills surrounded by cliff-like slopes (Pict. 3.38, 3.39). The slopes might be fragments of hills. Sometimes they are steep (Pict. 3.40, 3.41). They are usually more withered, almost oblate, due to the easiness of wind operation.

Craters (*crater*): Craters cover most of Martian land. There most common on the south hemisphere. They are almost omnipresent. Those rounded depressions, made by meteors drops, may be of different diameter—from a very small (tracks of small meteors) to a huge one—like Hellas or Argyre Planitia. Sometimes one crater overlaps another one. The section of Martian crater is in any way similar to those known e.g. from the Moon. It means that they look like a meteor would have dropped into a muddy terrain. Beds of large Martian craters are rather flat and smooth, covered with a layer of dust (Pict. 3.42, 3.43). Smaller craters are of a more rounded diameter (Caplinger 1994a).

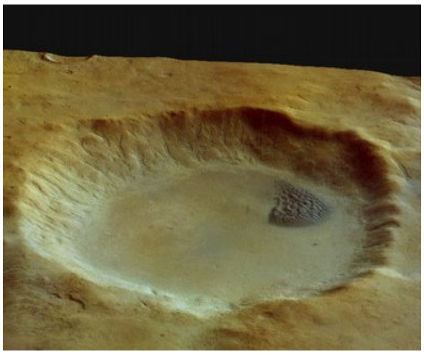
Described above land formations occupy relatively large, and even enormously large part of the surface. Definitions, outlines and pictures allow one to know in general a structure of Martian crust. However, to design a base, a living-working habitat, it would be crucial to know better some smallest pieces of those formations, that may look very diverse. On the basis of photographs taken by Martian probes there have been made three-dimensional pictures showing fragments of zoomed land forms. There can be seen differently shaped hills, escarpments and craters.

Martian hills may create single formations or groups of formations, and mountain ranges. They might have slopes diversified in gradient and more, or less, smoothed by winds. It might be noted that in some areas dominate one direction of winds, because a mountain range is gentle on one side, and on the other side it is more steep, and they are less withered. There are different kinds of hills in Picture 3.44: dome-like, table, steep and rugged. Hills are most common on the bottoms of large craters and depressions.

Slopes are seldom rocky, there are withered landslides and their carvings are smoother then. This shows that winds operation and dust layers change the outline of slopes. Landslides seem to be dangerous. *Valles* are often irregular in structure. They are seldom single, found rather in groups of adjoined valleys, separate valleys, winding, with widening parts, hills or hillocks in their bottoms. Their slopes may be steep and straight on one side, and on the other—cascading or sloping gently in some other part. Pictures of different slopes are shown in Picture 3.45.

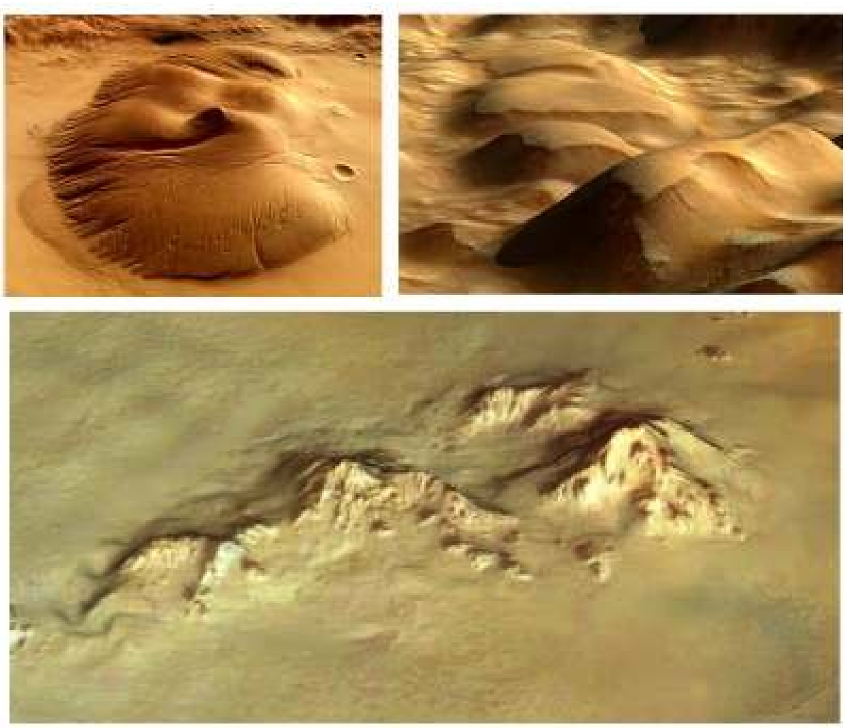


Picture 3.42: Large crater: section, axonometry

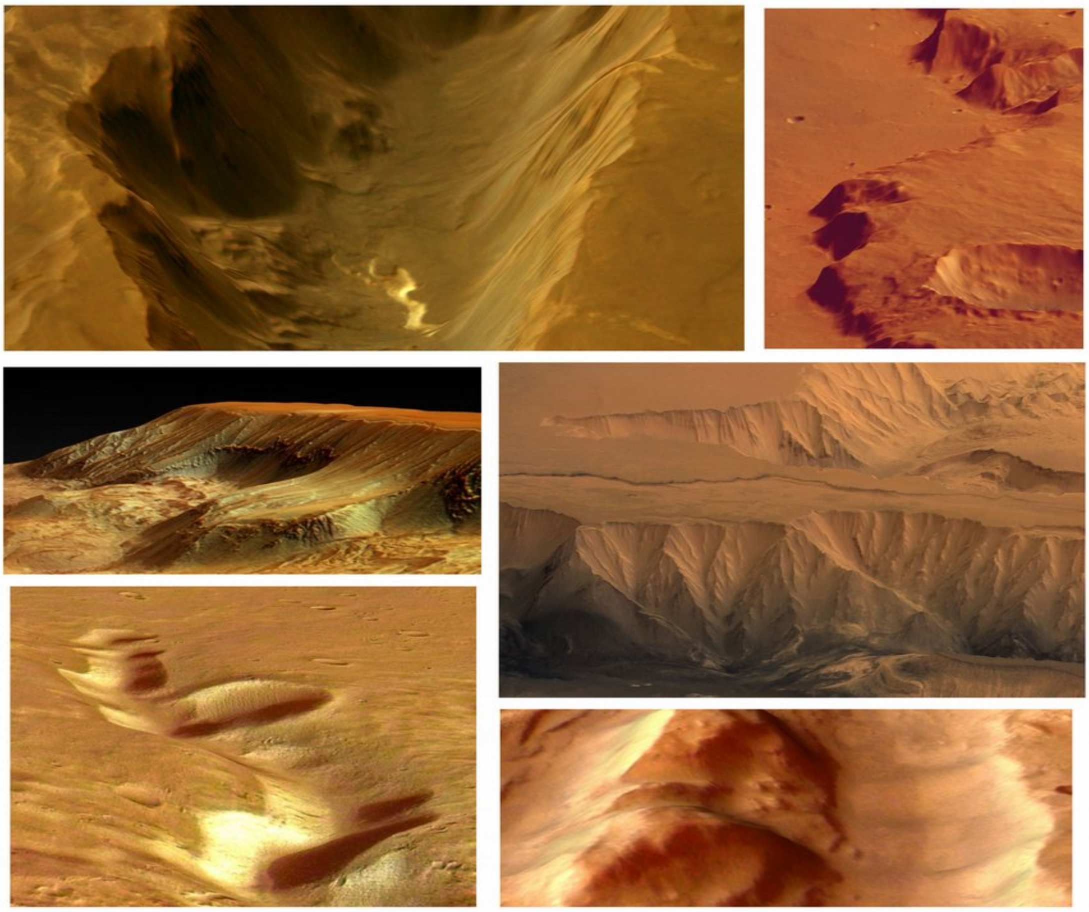


Picture 3.43: Crater Dunefield (ESA)

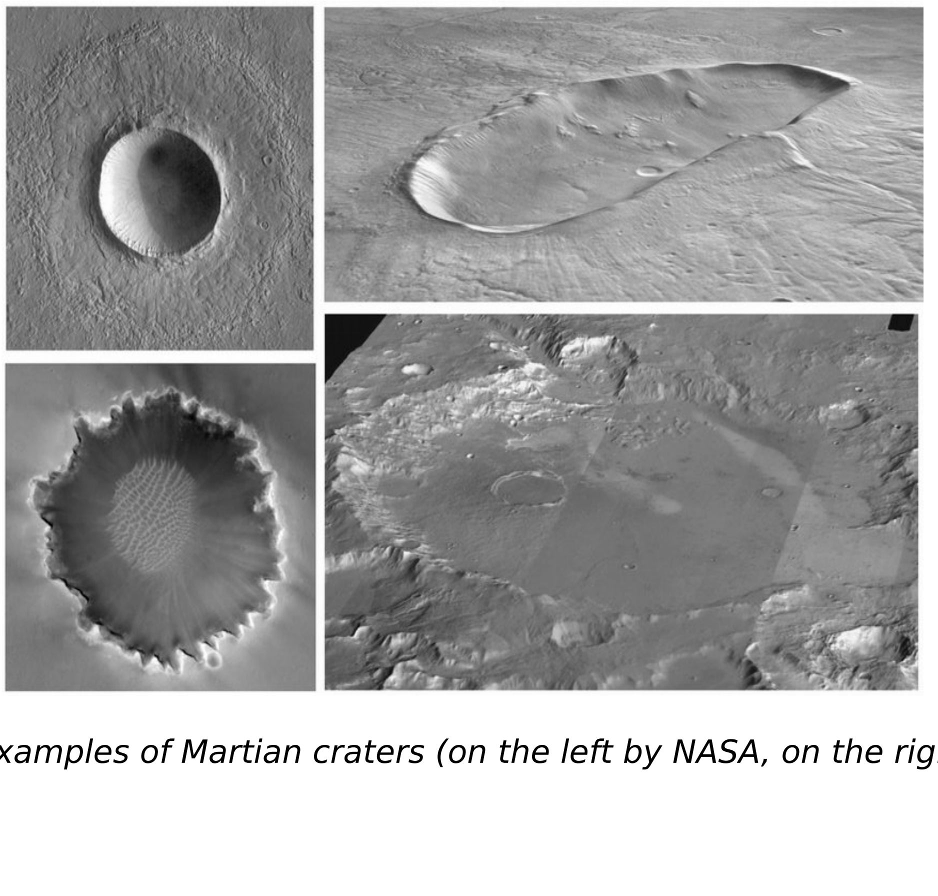
There are craters on flat areas, but they sometimes expand into depressions, and may overlap one another creating more complicated forms. Smaller craters are more regular and there are more of them, often adjoining one another. In Picture 3.46 there are different examples of them: a regular crater, a crater of irregular continuing circumference and steep slopes, an elliptic crater, and a huge crater, crossed with smaller craters.



Picture 3.44: Different examples of hills on Mars (ESA)



Picture 3.45 Martian slopes (ESA)



Picture 3.46: Examples of Martian craters (on the left by NASA, on the right by ESA)

The land formation influence on the architecture of Martian base

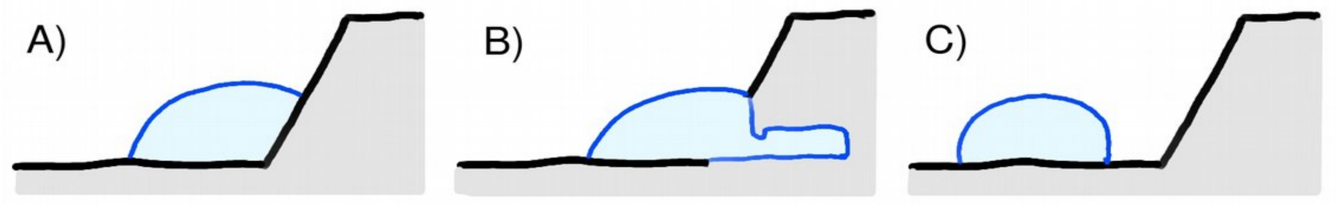
The architecture may concern differently on land formations, that is why there are three groups of concepts of Martian base:

1. Depending on topography, referring to specific forms, not requiring land transforming (Pict. 3.47 A).
2. A base located within the landscape and requirement of land transforming (Pict. 3.47 B).
3. Independent of landscape (Pict. 3.47 C).

The first group is a collection of such cases where a land formation is used for applying a specific architectonic solution. Qualities of existing situation are exploited. Relinquishing land transforming benefits with saving money and time, and also with avoiding importing special machines. However, that can result in deficiency of place for the habitat or lack of ergonomic shaping of the terrain. The best example of land exploiting could be to locate a base in a place surrounded by hills that would occlude it from winds that cause dramatic temperature changes. Another example here could be to localize a base in a lava tunnel on a volcano slope.

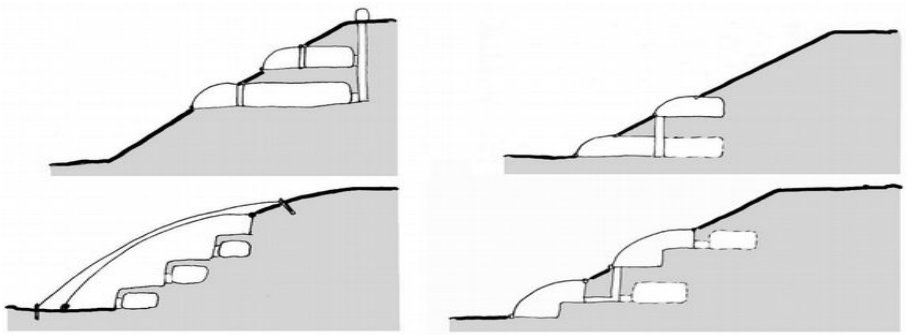
The second group is a collection of concepts of a base inscribed into the landscape applying on its relief, but still the ground needs to be transformed. The ground-works may be done in a larger or smaller scale. Land transforming can benefit with such enlargement of the habitat that it could easily increase comfort and ergonomics of the insides. A cubature is not determined strictly by the land relief; thus, it becomes more human-friendly and the area becomes easier to manage.

Some architectonic solutions are relatively independent of the land relief. Thus, there is no need to limit a project to one specific place to build Martian base. There are different technologies taken into consideration for the third group of concepts, and ground works are even sometimes not required. Hence this seems to be an affluent collection of ideas. However, execution of such ideas usually requires greater labor and materials input.



Picture 3.47: Different cases of architecture referring to landscape: A) a base located within an existing landscape, B) one put within a transformed landscape, C) one independent of a landscape

Base on a flat land: It might be recognized that such a base depends on land relief only partially, but still, it would be much easier to localize it on the north hemisphere, where most of the land is flat. A base might be build on the ground, or excavated vertically down under the ground.



Picture 3.48: Study concepts of multi-storey base located within a slope, an entrance atop or at the foothill

Advantages:

- easy to prepare a building site,

- good insulation,

- good area to build a landing pad in vicinity of a base,

- accessible easily from all directions,

- wide vision field.

Disadvantages:

- area is not wind-shielded; it is displayed to dust storms' operation and dust cumulation on buildings,

- large need of building materials.

Base on a slope (Pict. 3.48): Depending on the shape of a hill, its slope angle and height, the architecture might diversify in cases of building-in a base into a hill. A slope offers a plain to build windows or transparent barriers, hiding inside the hill area to exploit at the same time. Lots of the hills on Mars are very high so it would be rather difficult to manage them from the foot to the top. There should be first made a decision where to plan an entrance: at the foot of the hill, or atop. A slope also usually is not smooth on the surface, and it curves or winds mostly. It might be used for making wind barriers, there might be made cuts-in to make skylights for underground rooms from different directions.

Advantages:

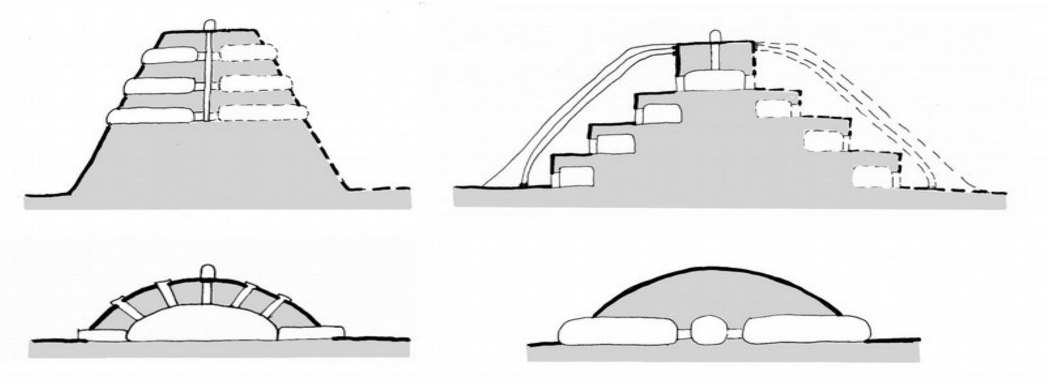
- more center-oriented habitat,

- partial safety form wind and dust,

- radiation protection (inside the hill).

Disadvantages:

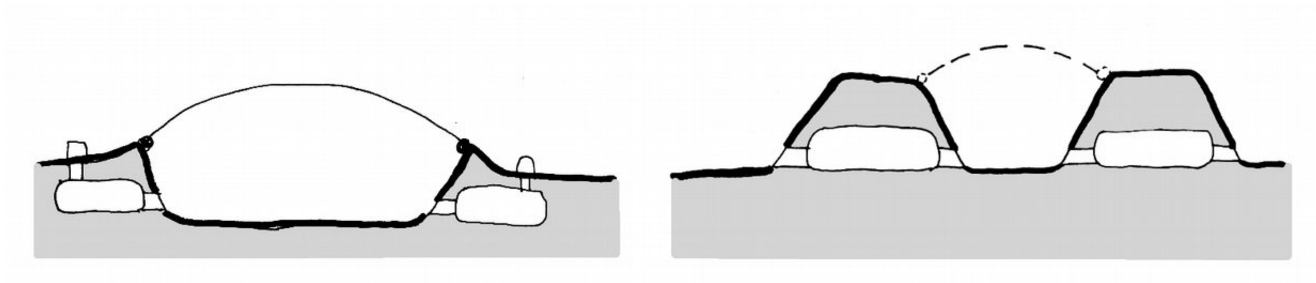
-insulation depends on the world orientation.



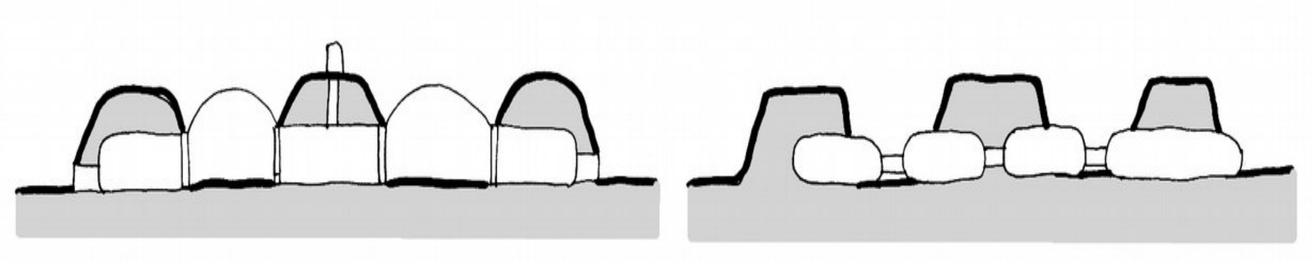
Picture 3.49: Outline concepts of multi-storey base located in a hill

Base inside a hill (Pict. 3.49): It might be designed almost the same as a base on slopes, if a chosen hill creates a mountain range with slopes both sides. There are dome slopes on Mars, too. They might be organized differently, creating more center-oriented base than in case of an extended hill.

Advantages:	Disadvantages:
- more consolidated habitat,	**-insulation depends on the world orientation,**
- lower need of levels than in case of a slope, thanks to managing both sides of a hill,	**-width of a hill restricts halls' span and reception of the sunlight.**
- wide vision field.	



Picture 3.50: Outline concepts of bases located in a crater and in a valley



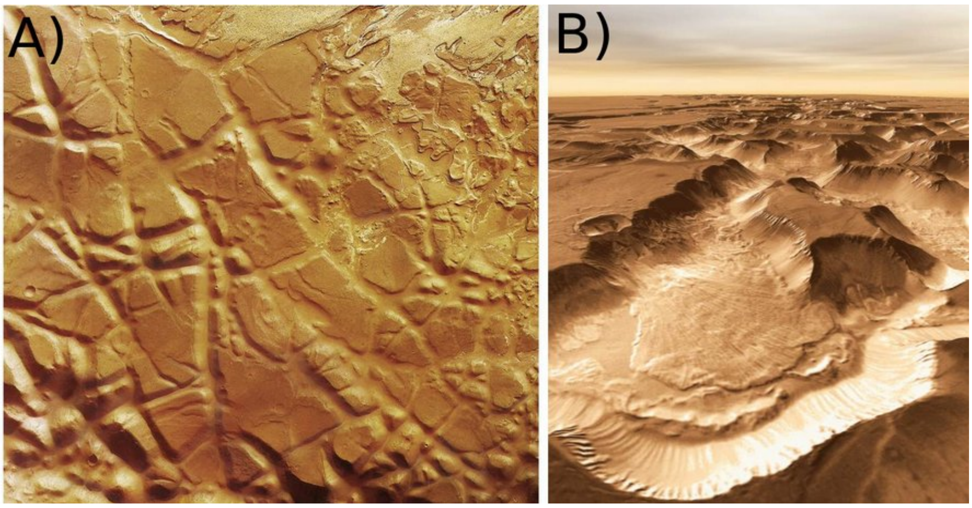
Picture 3.51: Outline concepts of bases located in a chaotic terrain

Base in a valley or in a crater (Pict. 3.50): If a valley is low enough, or a crater's diameter is not too large, their bottoms might be caulk to make connection between slopes, and as a result they would become external walls of the habitat, or they would shelter underground usable chambers and tunnels.

Advantages:	**Disadvantages:**
- good shelter from winds and dust storms,	**- worse insulation (depends on the depth and width of a valley),**
- slopes of a valley can become walls,	**- more dust collecting,**
- no need for external vertical barriers on sides of a base.	**- exit-lock leading to the bottom of a valley creates the need for additional solution of atop entrance.**

Base in a chaotic terrain (Pict. 3.51): A multi-module base is available in a chaotic terrain of collection of many hills, expanded in different directions. A part of the habitat might be located in many criss-crossing valleys and traversing many hills, creating a net of well-sunlit and radiation-proof space.

Advantages:	**Disadvantages:**
- more consolidated habitat, center-oriented,	**- difficult access to a base,**
- many possibilities of directing sun light: windows may be differently oriented, atrium possible,	**- restricted vision field.**
- shelter from winds.	**- no continuum of buildings, if travel-locks between hills would not be caulked.**



Picture 3.52: Labyrinthus Noctis: A) a view from above: an illusion of urban area (ESA); B) a computer created perspective (NASA)

A base may have advantages and disadvantages other than described above, what depends on characteristics of a terrain it is located in. A connection between the terrain and the architecture imposes one exact choice of area on Martian map, e.g. a hill should be open southward, on the lee side. In some cases it would be enough to build a hermetic carport to make a manageable cubature. A need for building materials would be minimal then, because massive slopes would provide most of external construction elements.

Conclusions for architect

1. The dominant forms of Martian terrain have been described. Their characteristic shapes and sections have been recognized. On the basis of these, there might be designed a concept project of a base consisting of habitable and working areas. Every place on the planet is exceptional, and to make a detailed plan of Martian base it is crucial to become acquainted with a specific building site.
2. Using a shape of Martian terrain seems economically profitable, because some formations may function as chosen construction elements, e.g. barriers, trusses, and less building materials would be needed in such cases. Localization all of the base inside terrain forms lower the need of materials down to the minimum.
3. Easier to gain and more functional insulation of underground chambers may be less complicated, when a base would be located in slopes, hills or in a chaotic terrain. On a flat terrain there would be need of cutting into slopes that would rise the cost of building or skylights should be enough. Sun light would come into the underground parts with a help of those skylights, but there would be no view of a hill. A view would be provided by using windows.

4. Martian slopes look differently. Some are withered and prone to disintegrate; others are stronger, with more stable section. The latter ones are better to build a base in them, because there is lower danger of landslides to occur; they are easier to prepare as a building site, because they are not covered in dust so much.
5. Slopes on lee sides, and not wind-warded, are better building sites. They would give better protection from dust and cold.
6. A base in a slope may have windows on one side only. The larger number of chambers with windows, the longer the habitat would be. This implies higher percentage of space for passageways, extending evacuation way from the furthest chambers at the same time. The problem might be solved by choosing the most protuberant part of a slope pendent above the main line of a slope, or to locate a base in a place where two slopes are easy to use. In that case it might be a hill, a single formation in a chaotic terrain or a slope adjacent to a crater.
7. *Chaos* terrain, especially *labyrinthus*, creates an illusion of urban area (Pict. 3.52). A net of valleys criss-crosses a kind of a small plateau, as if there were small cracks in it. Areas closest to the center of it are usually significantly less withered. Narrow canyons are easy to caulk, and in steep, not withered slopes there might be build many chambers with lots of windows. Chaotic terrains and labyrinths provide the best wind protection. Their additional advantage is that c*haos* and *labyrinthus* are mostly found near the equator, where there is a warmer climate. However, the supply of machines to a building site may become more complicated.
8. There are hills strongly changed by the aeolian processes and small *thola* in a shape of flattened domes. Those kinds of hills might be exploited to build a center-oriented, underground base. The smallest hills in that shape would allow planning windows on the perimeter; in bigger ones there would be an atrium inside, in the center (Pict. 3.49).
9. It seems, that the safest base would be build on plains, due to an easy access of transport shuttles. But it is crucial to remember that Martian plains are not flat in fact. There are lots of craters, and wind creates dust-whirls and dunes, that might be dangerous for a construction of the habitat.

4 Human Aspect

4.1 Human Survival Conditions on Mars

4.1.1 Survival Problem

Mars is an alien planet and there are dramatically different conditions from those that they are on Earth (see section 3). Human beings are not used to live in such environment:

- atmosphere is too thin and too low in oxygen to be suitable for breathing;
- lack of moisture in the atmosphere would cause skin to dry rapidly;
- lack of liquid water precludes straight forward drinking, washing and gardening water supply;
- low temperatures and often rapid changes of temperature in short time may cause drastic chilling of the body and lowers its stamina;
- very tiny and harsh Martian dust in the atmosphere can penetrate lung while breathing in the air, and cause scratches in the epithelium and damages of internal organs;
- electrified dust particles rushing at great speed during dust storms may cause skin abrasions and unpleasant electrostatic unloading;
- dwelling on the surface during solar storms may be life-threatening because of a fatal dose of radiation or causing radiation illness;
- long term cosmic radiation exposure on the surface of Mars (especially on high-level terrain) may cause radiation illness and increase danger of cancer.

There might be also chemical danger on Mars, even if current researches do not prove it (ASEB 2002). Also there is taken into consideration a danger of alien life forms that may occur on the planet. [1]

There is a wide range of different means of protection of a human being from the danger described above, providing them safety on diversified levels of sophistication:

(a) Martian suit

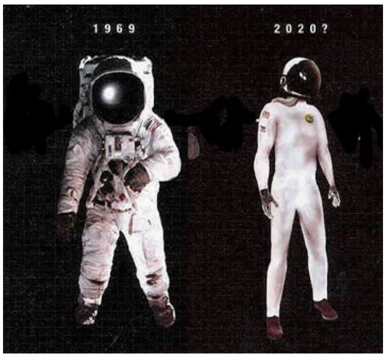
(b) staff vehicle (mpv)

(c) provisional shelter

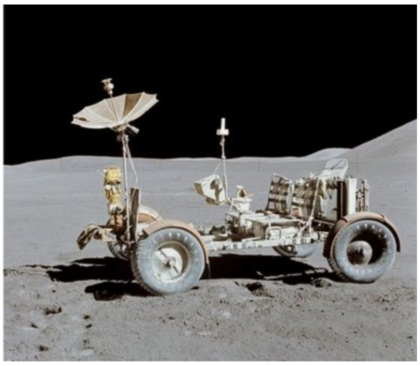
(d) a small habitat (station)

(e) a big habitat (base)

1 An objective of the soonest planned missions inter alia by NASA is searching for life forms on Mars.



Picture 4.1: Space suit and planned Martian suit (David 2005)



Picture 4.2: The Moon vehicle of Apollo 15 mission (NASA)

Picture 4.3: A model of Polish mpv vehicle (Mars Society Poland)

Martian suit would allow a human being to walk on the surface of the planet (EVA: *Extra Vehicular Activity*). A prototype of modern Martian suits are outfits made of light elastic fabric, like a thin layer applied onto a body, which allow full flexibility and comfort of movements. One being currently designed in MIT (Massachusetts Institute of Technology) Bio-Suit System for a Martian suit (David 2005) assumes embroiling a system of artificial muscles into a fabric, which would enhance the strength of human muscles and their stamina in Martian conditions. Anti-electrostatic outside layer would restrict dust from hanging and settling on the suit. A mixture of gas to breathe would be pushed under the right pressure into the helmet and into the system of pipes inside the suit reaching to the gauntlets and boots connected hermetically with it. Such a light, easy to put on and off suit, would be made-to-measure for every crew man of the mission (Pict. 4.1).

Martian suit would allow conducting direct researches of Mars and walking on the surface of the planet. However, protection it could assure would be always limited, and time of using it would not be very long. The main problem is oxygen supply that would be disposable, next, there is the problem of recharging or exchanging batteries for the systems of sustaining the efficiency of this complicated suit, and, last but not least, limited protection from cosmic radiation and insufficient protection from solar radiation. The suit would be suitable for walks during favorable weather. However, it is impossible to drink, eat or wash etc. while wearing it, and that is why it is insufficient for long-term exploitation, and is not suitable for long-term exploration of Mars by people.

A mobility of a human being, especially in a strange and alien environment, in extremal conditions, is limited, thus, their available range of exploration is also limited. To explore larger area of Mars people require a larger vehicle. To cover short distances a small vehicle would be enough, one similar to those that have been in use on the Moon during Apollo mission (Pict. 4.2). However, people have spent on the Moon several days only, so they could not go farther from their Space shuttle, which would take them back to Apollo waiting on the orbit. Martian mission are to take significantly more time: due to DRM assumptions the exploration of Mars should take about 1,5 year. That time should allow exploration for a larger part of Mars. Thus, a sophisticated vehicle is required there. Five groups of scientists from all over the world (including one from Poland), which belong to Mars Society, are working currently on the project of the best and the most economical pressurized Martian vehicle mpv (*mars pressurized vehicle*). The plan is to keep artificial breathable atmosphere inside a vehicle, with an airlock as an entrance. A sophisticated apparatus would recycle water, air and waste. Mpv would imitate a common caravan containing a bedroom and a kitchen that would enable people to travel a dozen, or even more, days. There is a model of Polish Martian vehicle shown in the Picture 4.3 (Mars Society 2007).

However, during an expedition, far away from the landing pad of a Space shuttle, it might occur that a Martian crew finds an interesting terrain, where they should conduct researches and collect test samples, but the vehicle could not reach the place because of e.g. too much roughness of the area. Then it would be needed to be able to take a portable shelter for a walk, similar to a common tent used on Earth. This is crucial that such a shelter should be light, easy to put up and take down again, and it needs to be practical. At the same time it is favorable that the shelter would keep inside artificial breathable atmosphere and give protection from wind, dust and cold. Still, as a portable shelter, it should be comparatively lightweight, however, it would be the cause that staying inside for a long time would be impossible because of a limited quantity of oxygen inside. That is why a **habitat** is needed: a human-friendly place to live and work. Contemporary plans of Mars exploration anticipate the function would be fulfilled by a small module (station). The station would be larger, heavier and more complicated than a tent, and this is why it would be less adapted to take down and carry to the next stop. However, the comfort it would provide people with, should be enough to function as a house and a a workplace for the crew during the time on Mars. Such a module, as a Martian station, would imitate in function and cubature polar and Space stations (see section 5). However, it would not be a habitat providing a high life standard. Due to its size it would create a limited and stressful life-and-work place. A real comfort to live and work during a long-term mission on Mars would be created only with a comfortable and fully equipped Martian base. There would work the same life support system what in an mpv, a shelter or a station, only it would be more productive.

Every danger emerging from the external environment is connected with diverse requirements to the habitat on Mars (independent of its size: a small station or a large base):

- there might be artificial atmosphere similar to one on Earth, breathable;
- the temperature inside should not fluctuate much (i.e. under external influences) and it should be comfortable for people;
- pressure and temperature should be adjusted so as to keep water in its liquid state;
- the outside, the surface, should be kept safe from Martian dust, and in case of danger of dusting, it should be possible to clean it easily;

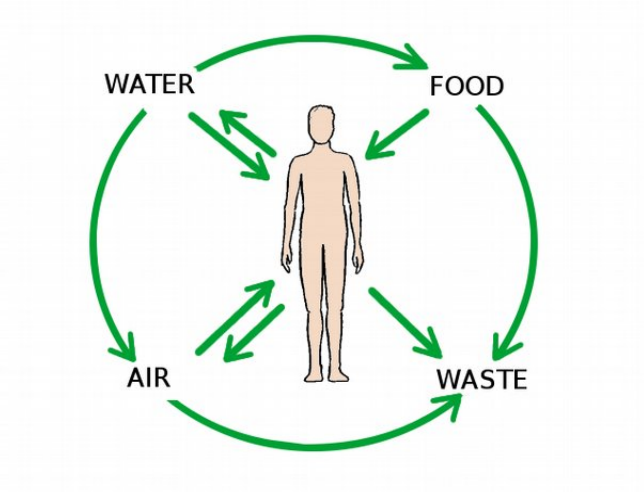
- the insides, intended for constant dwelling of people, should be protected at the most from the Space and solar radiation;
- the insides should enable people to move around easily in an environment of lower gravitation.

4.1.2 Life Support System – LSS

LSS is an abbreviation of *Life Support System*, what implies a combination of different instruments, to support all life functions of a human being. The system is used in a hermetically isolated place, cut off from the extreme conditions of surrounding environment. Thus, it is a crucial system of instruments in every kind of Space habitats, including Martian base. LSS artificially imitates mechanisms which take place in the Earth's ecosystem and to which a human being's organism is used to. The system supplies everything what is crucial for a human being to survive: adequate air, clean water, food; it also takes care of garbage and waste. Due to those four functions of LSS, it is divided in four subsystems:

- Atmosphere Managing Subsystem;
- Water Managing Subsystem;
- Food Managing Subsystem;
- Waste Managing Subsystem.

Every subsystem consists of different cooperating instruments to maintain the main objective, it is the imperative of the said subsystem. Subsystems cooperate with each other and they depend on one another, because they all create adequate life environment in a habitat. Earth's ecosystem naturally recycles by itself: waste created by some organisms is used by others. LSS imitates those mechanisms artificially in a much smaller cubature. Additionally, it should adapt to a strange environment, e.g. it is crucial that it would work efficiently in an environment of 0.38g on Mars. A scheme in the Picture 4.4 shows a reliance among a human being and every LSS subsystems:



Picture 4.4 A reliance of LSS subsystems

- human being takes oxygen from the atmosphere and gives back carbon dioxide;
- human being takes clean water and gives back foul water and urine;
- water is send into atmosphere to keep adequate humidity;
- water is crucial for food preparation;
- human being takes food;
- waste are: food remains, used packagings, dirt removed from water, faeces and urine.

Atmosphere Managing Subsystem: Tasks of the subsystem are (Dursap and Poughon 2001, Henniger and others 1996): disposal of carbon dioxide and supplying oxygen, revitalization of the atmosphere; the chemical control of the atmosphere; the pressure control of the atmosphere; the temperature control; constant monitoring of the atmosphere quality (searching for fungi and bacteria, and pollution control), and smoke monitoring.

The Earth's ecosystem realizes most of the tasks that regulate the atmosphere behavior as a unit in specific parts. On the whole, the Earth's atmosphere supply people with oxygen, removes metabolic products (gas in vestigial quantity, and carbon dioxide), and it regulates temperature, pressure and humidity with physical and biological processes[2]. It is crucial that exactly the same operations take place in enclosed ecosystems, although, they are much smaller ones. As Mars and Bust team says (2003, p.60), the main objective of the atmosphere managing subsystem job is maintaining atmosphere acceptable for a human being. The temperature control system takes care of sustaining humidity between 25-75%(50% optimal), and

2 Even if the conditions changes relatively to the elevation and latitude.

temperature between 18-26.7^{O}C (21^{O}C optimal). Oxygen supply is around 1 kg per person for one day in the atmosphere to breathe, considering possible additional loss (oxidization in the environment around). Assuming that during EVA some leaks are unavoidable, in the cabin there must be maintained pressure 210 h Pa, fluctuations between 195 to 230 h Pa are acceptable (Mars or Bust 2003). LSS instruments control pressure of all gas in the habitat's atmosphere not to exceed given standards. Allen and others (2003) say that atmosphere can not consists of oxygen only (and exhaled carbon dioxide), because it would be very thin and fire danger would be very high. Human organism would not function properly in such homogeneous atmosphere; they would have problems with taking an accurate, non toxic, quantity of oxygen—proper for the body to function. That is why it is necessary to use neutral gas, like nitrogen, or argon. They should be transported to fill in any leaks or to be gained *in situ*, from local sources, what would require additional instruments.

There should be taken into consideration different directives to plan a specific pressure in the habitat. However, the most suitable pressure seems to be the same as on Earth (1013 h Pa), but a lower one would be acceptable, what is proved with several researches on Skylab (see section 5). Allen and others (2003) give a list of different reasons why there should be thinner atmosphere sustained in the habitat than it is on Earth. When there is a higher difference between the pressure in the habitat and the external one, than what follows is:

- it takes longer to prepare EVA—so called *pre-breathe time*—necessary to prepare an organism to different environment[3];
- construction has to be characterized by higher level of durability not to be rent;
- instruments creating and sustaining the atmosphere in the habitat would work longer, what should result in higher level of energy consumption;
- more energy is needed to decompress airlocks and to fill them with oxygen again;
- loss of gas through construction or airlocks becomes more severe;
- *pre-breathe* takes more time and it slows down mission work, and it is exhausting for people psychically and physically.

  At the same time the pressure in the habitat should not drop below an acceptable level, because:

- the sound transmission becomes worse (form the point below 690 h Pa), that results in communication problems (noted e.g. on the orbital station Skylab);
- there is higher level of fire risk;
- a body chills faster when sweating or after having a shower, when skin is wet;
- boiling water takes longer and it results in delays in food and drinks

3 This is an especially serious problem when, due to some reasons, a sudden evacuation is necessary and there is no possibility to stay any longer than crucial in an airlock.

preparation, especially when boiling water is crucial to destroy micro-organisms (most bacteria flora is destroyed in temperature $60^{O}C$, but there are bacteria resistant to hot water which need temperature $120^{O}C$ to be destroyed) (Allen and others 2003).

The atmosphere managing subsystem is responsible also for removing different unnecessary kinds of gas, smoke and pollution (dust, fungi spores, bacteria etc.). Assuming that there is 0.85 kg of carbon dioxide per person for one day, exhaled and a technological by-product of instruments working in the habitat. People, materials and instruments generate different organic and non-organic substances that spread in the environment inside, e.g. ammonia, nitric oxide, methane, ethylene and benzene in the state of gas. They must be intercepted not to allow their level to exceed standardized norms of SMAC, Spacecraft Maximum Allowable Concentration, their values are following: 7 mg/m^3, 0.9 mg/m^3, 3800 mg/m^3, 340 mg/m^3, and 0.2 mg/m^3 (Mars or Bust 2003).

Conflagrations tend to reduce and extinguish by themselves finally on Earth, but in an enclosed environment a quick reaction to extinguish fire is crucial, but still, the best option is to take every possible precaution not to start it. Fire is dangerous for human life and health, instruments damage and the loss of precious oxygen (Mars or Bust 2003).

Water Managing Subsystem: Tasks of the subsystem (Dursap and Poughon 2001, Henniger and others 1996): drinking water supply, hygiene water supply, food preparation water supply and economic water supply (recycling sewer water and chemical production of water); sustaining sufficient humidity in the atmosphere; monitoring of quality, quantity and chemical composition of supplied water, and completing water storage.

Mars or Bust teams says (2003, p.70) that the main task of Water Managing Subsystem is to supply drinking water and economic water for the members of the crew during the whole mission. It is assumed that a six-persons crew needs 4 liters of drinking water and 23,5 liters of economic water per day. Water might be recycled or gained form local Martian resources. Its quality must correspond with quality requirements. Water must be examined and presence of micro-organisms must be analyzed and, in case of their presence, it must be treated not to endanger people's health. For security reasons water monitoring must be constant.

Food Managing Subsystem: Tasks of the subsystem (Dursap and Poughon 2001): supplying food; food preparation; food storage and quality control of food contamination and corruption.

Food Managing Subsystem tasks are to store food properly, e.g. dehydrated food or frozen food. The system is ready to acquire food when it is equipped with many elements to cultivate plants, and to inbreed and rise animals. It may occupy even several chambers. It should be equipped with farming machines, cultivation or acre containers, cans with plant seeds, harvest containers, and a suitable illuminating system. The system is also responsible for food preparation (Dursap and Poughon 2001), i.e. it should be also equipped with devices like a kitchen robot, a microwave oven, a kettle etc.

Waste Managing Subsystem: Tasks of the subsystem (Dursap and Poughon 2001, Henniger and others 1996): collection and storage of solid waste; collection and recycling of urine; not-recyclable water collection and storage; segregation and recycling.

Waste Managing Subsystem is responsible for efficient collection, storage and recycling solid, liquid and gas waste; i.e. it collects food remains, used packagings, used filters, gas collected by the Atmosphere Managing Subsystem, urine, faeces, used hygiene and drinking water, dust and others. The management of different waste may be diversified: waste not available for recycling should be stored separately and in different ways from waste that might be recycled. The subsystem should also channel waste to other devices or places to recycle it (Dursap and Poughon 2001). The more waste is recycled, the less storage space is needed, what helps to avoid Mars pollution.

4.1.3 Resources for Life Supporting System

There are four crucial resources required to support life in Martian habitat: storage, physical-chemical regeneration, bioregeneration and reprocessing local resources. Every one of those has its advantages and disadvantages, and every one works in regards to different rules; they influence architectonic solutions for the base: its functional system, and the quantity and specification of rooms.

Reserves

This is a source of resources crucial to support life, which has been used during Space missions. This is the easiest way to provide habitants of an outer-space base with food, water and oxygen, because it does not require any sophisticated instruments, storage rooms only. However, this solution is acceptable only for short term missions (Drysdale and others 2003). The longer time of staying in the Space is, the more reserves people need. Firstly, small habitats do not have much space at their disposal. Secondly, many food products are characterized with a too short expiration date. Thirdly, the larger reserves, the higher costs of launching the rocket. Large quantity of reserves rises the cost of transportation so much that it is completely unprofitable, when compared to the fact that there might be possible any other resources of reserves of food.

However, some of the reserves should be taken from Earth. Those are the things which production on Mars would be impossible or really troublesome, e.g. clothes, pharmaceuticals, spare parts of LSS, tools etc. Among the reserves, there should be things of highest quality, checked and proved on Earth. There are advantages of this situation: people would take from Earth some specific things, like their favorite food, which would help to overcome stressful situations (sweets, favorite food, spices, animal food [in case of no possibility of raising animals on Mars]).

Resources to support life which need low temperature require freezers and fridges to store them. However, the author notes, the Space and Mars are so cold that the temperature there is considered to be adequate to protect food against hot sun rays, and their transportation, in an adjoining capsule, should be taken into consideration. The transportation of frozen food would be complicated only because of the water weight it contains, which rises its weight. Dried food is a much cheaper solution and it does not require sophisticated storage rooms or instruments with high energy consumption (Dursap and Poughon 2001), but this method requires waterproof and vapor-barrier packagings.

Physiochemical regeneration—PC

Physiochemical regeneration in a Space habitat takes place with the help of different devices, which are sustaining air purification and oxidization, regeneration of the atmosphere, food and water, along with waste products exploitation. The production process of such apparatus has started along with construction of the first Space stations, and it was to be provided for the Moon mission. The project has taken over fifty years to improve the apparatus,and it has resulted in production of an extraordinarily productive and dependable equipment. Drysdale and others say (2003) it regenerates water and air perfectly. Its precision and reliability make them the most efficient LSS system contemporary, and they are in use at the International Space Station. Other systems may become more competitive in case of long term missions to further regions of our Solar System only (further then Earth's orbit, or the Moon). Their main disadvantage is their lack of possibility of refurbishing food reserves[4]. At the same time other LSS systems could not work independently yet, and that is why it is required to depend on PC LSS until they would be able to work so. That system is also irreplaceable in case of any problems with with bioregeneration or reprocessing local resources. Thus, it would seem as an ideal supply and security base of help to other systems.

PC LSS consists of a wide range of different equipment that, despite of constant attempts taken up to limit their cubature, they still occupy a lot of space in small habitats such as Space stations. They, along with the monitoring and researching equipment, occupy almost the whole available space on the habitat's walls, and it is visible in Pictures 4.5 and 4.6, and it is also visible that they are the causes of the artificial looking of the inside environment, and its lack of comfort people need (emotionally and visually).

Modern technology allows PC LSS apparatus to be improved. At the same time, more precise instruments are being invented. To repair such equipment, there is

4 Unlimited resourcing of food has not been discovered yet, there is only some amino-acids production possible nowadays.

usually an expert needed. Thus, it is crucial that at least one of the members of the staff during every Mars mission would be such a required expert. Otherwise, there is a risk in case of failure there would be impossible to get any outside help from Earth, as it has happened to Apollo 13 mission to the Moon, as the delay of electronic transfer of data and communication is significant. However, it should be noted that the long term exploitation of such equipment is guaranteed, and possibility of its damage is low. Their main drawback is that they need many spare parts, especially filters. They should be taken with the PC LSS equipment, but they would occupy a lot of storage space. The longer the mission is, the more spare parts occupying storage rooms there are. However, as Drysdale and others say (2003), the use of PC LSS even during a several-years-long mission is still a cheaper solution when compared to other life supporting systems.

Picture 4.5: The whole wall–space in ISS is covered with sophisticated apparatus (NASA)

Picture 4.6: People are squeezing between lots of LSS and monitoring instruments, and research equipment (NASA)

Hamilton Sundstrand[5] is one of the producers of PC LSS working for NASA. Here are some of their products made for International Space Station and Space Shuttle:

Common Cabin Air Assembly: an integrated instrument to manage internal atmosphere in an enclosed habitat. Its functions are: sophisticated air conditioning, condensing heat exchanger, temperature and humidity control. The result is that the instrument, because of modern technology and the use of more adequate materials, is extraordinary silent, small and productive, and it is characterized by a low energy consumption (Pict. 4.7).

5 Information about their products – check website: hsssi.com

Intermodule Ventilation Fan: a ventilator supporting stability of temperature and oxidization of the atmosphere. Its noise level while working is equal almost 0 dB. This assembly mixes air to keep the same temperature in every room, despite of diversified physical activity of crew members and heat radiating from different parts of equipment in the habitat. This ventilator is adapted to a constant and long term exploitation (Pict. 4.8).

Bacteria Filter: this is a specific kind of a filter purifying the atmosphere from bacteria and tiny despoilments. It can remove 99.9% of mites if they measure at least 0.3 micron. Its filters are replaceable. It is build for 24/7 exploitation: it does not overheat and a quality of filtering does not get worse because of its long-term exploitation. The bacteria filter is build from light and durable materials, such as fiberglass and aluminum (Pict. 4.9).

RCRS: this is an instrument to remove carbon dioxide from the atmosphere in the habitat. Thanks to the innovative method of collecting CO_2, no by-products are created, and the sorbent inside RCRS does not need energy to auto-clean. Those advantages seems to be especially important in case of a long-term Space mission (Pict. 4.10).

Picture 4.7: Common Cabin Air Assembly (HSSSI)

Picture 4.8: Intermodule Ventilation Fan (HSSSI)

Picture 4.9: Bacteria Filter (HSSSI)

Picture 4.10: RCRS (HSSSI)

Picture 4.11: WPA (HSSSI)

Water Processor Assembly (WPA): this is an instrument to depurate water. It can process about 55 l of water-waste per day into high quality drinking water (suitable for NASA standards). WPA is very productive and completely autonomic. It is also equipped with damage detector, leak detector, and incorrect action detector. However, it is very big, it is almost the size of an average closet (Pict. 4.11).

Some architectonic tips for PC LSS:

1. The instruments' arrangement in the available space inside should be directed by specified requirements. It is crucial:
    - to assure their best functioning, e.g. with even positions of filters;
    - to make sure they are close to places they serve, e.g. water cleaning devices should be next to kitchens and bathrooms;
    - to save cables they should be as short as possible;
    - to minimize noise reaching the rooms designated for constant exploitation.
2. For LSS instruments there should be sufficient places planned; there might be cabinets, or even separate rooms. It is crucial to make sure they are accessible without obstacles.
3. LSS instruments should be covered:
    - aesthetically, to lower the artificiality of the environment;
    - acoustically, to lower the noise in the habitat;
    - for security reasons, to eliminate accidental damage of those instruments.
4. If it is possible, it is worth locating LSS instruments in one technical room, accessible for people in case of its failure, when a part should be replaced (e.g. a filter), and to monitor it. It is also easier to insulate acoustically one room instead of several or more rooms, or to do so with every single instrument.
5. It is indicated that a console screen should show different LSS instruments monitoring data, and that it would be possible to control it and to enable manual control of e.g. air humidity, temperature.
6. Single instrument's productiveness may influence optimal and/or maximal cubature of rooms, e.g. in case of air-conditioning.
7. LSS instruments may be planned with specialist's assistance only.

Bioregeneration (BIO): bioregeneration means using alive organisms in LSS to recycle atmosphere and water, and in food production, where waste products are for exploitation. BIO LSS is the only system that might be completely closed, because it ensures food production (it is independent from irreplaceable reserves). Without bioregeneration a long term manned mission to Mars seems impossible.

The basics of correct functioning of BIO system (Lewandowski 2000):

a) closed air circulation;

b) closed water circulation;

c) closed organic matter circulation;

d) circulations must process due to natural transformation and biochemical reactions;

e) there should be assured specific light for cultivation;

f) there should be assured specific soil for plants.

BIO LSS seems to have lots of advantages. It could become in 100% closed circulation and it could ensure almost an unlimited atmosphere, water and food regeneration. This seems to depend on sophisticated devices only at minimum scale. What Drysdale and others note (2003) food production is assisted by water and air regeneration, when food is being produced, oxygen and water vapor are released to atmosphere, and carbon dioxide is removed. All of the metabolic human needs are realized with this one process. This system is the closest one to the natural ecosystem for humans, thus, it is the one best received by humans. Additionally, lots of green plants, flora environment, flavor of plants and taste of fresh food can foster a much better state of being of habitants in Martian base (NASA ALS 2004).

BIO LSS is competitive to PC LSS, but there is still the need to rise the system productivity. Bioregeneration needs sowing more plants only, contrary to physiochemical processing that needs larger amount of instruments, which—comparatively to the seeds amount—is relatively heavy, expensive, and needs lots of spare parts. Today PC seems to be cheaper than BIO, but only for shorter missions (Drysdale and others 2003). Long term Mars missions seems to become more economical with bioregeneration exploitation. Especially water regeneration bio-reactors do not need filters, they do not cause waste collecting etc, and PC LSS systems do. Thanks to fresh food production, BIO LSS needs food supplies only at the onset of the process, until it is time for the first harvest; it is contrary to PC LSS, which requires large food supply for a long term mission.

However, a life supporting system supported with bioregeneration is much more difficult to plan, contrary to systems supported by machines only. It is also not as predictable and calculable as PC LSS, because natural ecosystems dependency are not as well-known as physiochemical processing (Henninger and others 1996). Different plants grow in their own characteristic time. Seasoning, and the order of cultivation should be planned in details, not to allow any oxygen, humidity and food deficits or excesses.

BIO LSS needs some time to prosper completely. Thus, at the beginning of such a mission BIO LSS and physiochemical system have to be coordinated. As researches prove, water purification needs 1-3 weeks to become efficient, and it needs one month to achieve complete atmosphere regeneration (Drysdale and others 2003).

Closing the circulation occurs at the end: one month is the minimum required time to grow first vegetables, and three or four more to grow first grains.

There are three kinds of cultivation as Drysdale and others (2003) note:

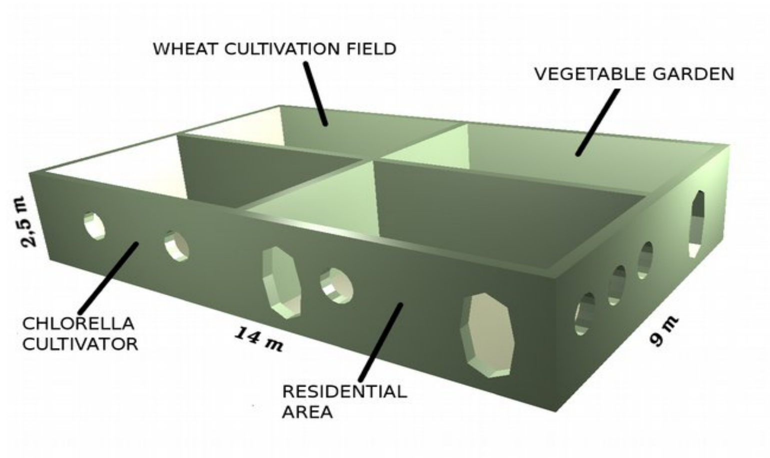
a) basic cultivation, containing lots of nutrients: grains, potatoes, sweet potatoes;

b) low capability cultivation, ensuring fats and proteins production, e.g. rapeseed.

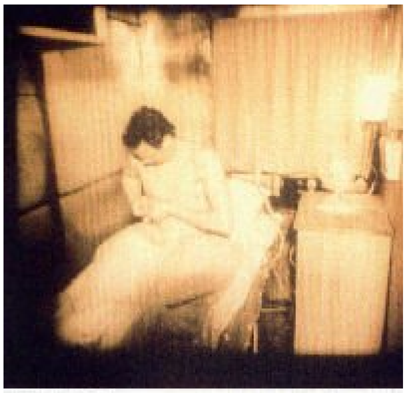
The balanced diet for the habitants could be assured by the right assortment of plants, as well as balanced water circulation and gas exchange in atmosphere. It would keep the balance between edible and non-edible biomass, where the latter would be used to produce energy, to compost it, or as forage. To ensure the balanced amount of oxygen, water vapor and food production, sowing and harvesting time should be very carefully planned for every plant. This seems to be a very complicated problem to solve.

Drysdale and others (2003) note that water amount seems to rise in closed food bioregeneration circulation, that might cause humidity rise in atmosphere. This is a detrimental situation, it may induce fungi, mould and algae growth, and that should be avoided. In case it is not, they should be removed at once. Drysdale and others (2003) suggest collecting any water surplus into water tanks to build radiation barriers.

c) vegetable cultivation, ensuring fresh food rich in vitamins, e.g. lettuce, tomatoes, spinach, onion and different herbs;



Picture 4.12: Bios-3 scheme



Picture 4.13: Private room (biospheres.com)

Cultivation work, and possibly, even raising animals, would become for habitants of Martian base a way to relax from a strange reality on a distant planet. However, it should not occupy too much of their time and take them away from their duties connected with the mission. That is why, Drysdale and others (2003) point out there would be some cultivation machines planned for mission to do the job. Bio-Plex project suggests a detailed specification of machines to send there to do so

(Naghshineh-pour and others 1999).

Researches conducted on bioregeneration for the manned Space missions started in the 1950s of the 20th century. Since that time BIO life supporting systems have been tested in different simulations. Every simulation have had slightly different characteristic, but the general idea, common for all of them, is that alive organisms should be exploited for recycling in closed ecosystems. The idea is to grow and reproduce plants to collect carbon dioxide exhaled by people and release oxygen to breathe. Waste water is used for watering plants and clean water is collected during respiration and vapor process. At last, plants are the source of food, vitamins and mineral salts for the simulation's participants. Some of the plants are perennial and produce edible fruit, other plans produce seeds for sowing, and other edible plants for a following season. The best documented and researched simulations of BIO LSS are: Bios-3, Biosphere 2 and LMLSTP.

Bios-3 is an artificial ecosystem where there were conducted three science experiments with human participation in the 1970s and 1980s of the 20th century. The first one took place in 1972-73 and lasted for 6 months. There were two participants, a woman and a man. The second one took place in winter 1976-77. Three men[6] lived in Bios-3 for 4 months. And the last one took place in winter 1983-84 and lasted for 5 months, and there were two participants, two men (Salisbury and others 1997).

Bios-3 has been designed by Boris Kowrow (physicist and biologists). This is an easy modular construction, and it enables some a configuration choice. There are four cuboid modules, 7m x 4m and 5m x 2,5m, connected with each other, creating one hermetically closed complex on a rectangular plan of a size of 14m x 9m (Pict. 4.12). Every cuboid is equipped with 3 doors to assure connection in any configuration, and at the same time the continuity of passageways, and a fast evacuation passage if needed. The evacuation time limit is 20 seconds. One of the modules is planned to become a habitat, and three others to function as phytotrons[7]. There are three private cabins in the habitat module (Pict. 4.13), every one with a small window installed in the wall, which could be covered with a curtain, viewing the inside of a bio-chamber. There are also a kitchen, a bathroom, a monitoring room, a studio and a technical room with LSS systems.

The whole complex was put underground and insulated from any outside climate factors. The artificial light was supplied with xenon lights, and they had to be working all the time in the cultivation modules. Due to their continuous work of large intensity they had to be cooled constantly with water revolving around the lamps in hermetically closed lampshades (water jackets). The intense light for cultivation area was provided to intensify their growth, but it had a poor effect on some of them: tomatoes and potatoes need the night rest, when they grow their fruit and bulbs.

One of the phytotrons has been adapted for grains cultivation only as the base of

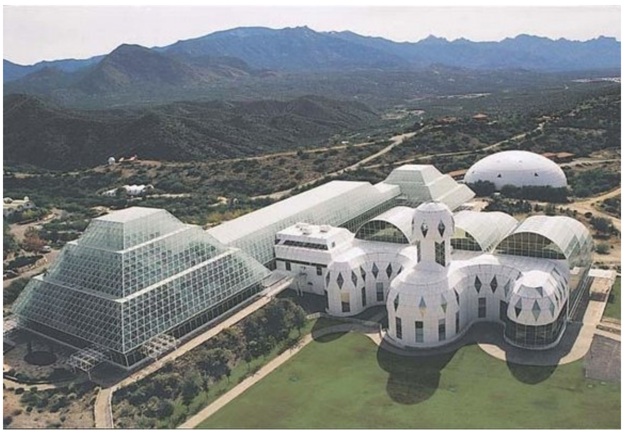
6 There were three men only, until one of them resigned from the experiment during the simulation.

7 Phytotron: an air-conditioning plant-growth chamber for artificial environment researches (PWN 2006).

food production, the second one for vegetables cultivation, and the third one was adapted for algae cultivation as a main source of oxygen to breathe. The algae production was unnecessary as they appeared to be not a good source of vitamins or food, and their over-intensified growth caused over-production of oxygen, and the bionauts had to burn hay to lower oxygen amount in the atmosphere. It was very difficult to keep the right amount of algae population. It was also proved that people are not used to eat algae food: it can cause illness.

Plants could purify water well, but some extra instruments were also in use to improve its quality. The system capability reached almost 85%. The food production assured around 20% of food for bionauts, the rest came from food supplies. As a result, apart from the space for grains mill and for baking bread, there had to be assured some space to store food supplies.

The analyses of Bios-3 simulation proves that in a 99%-closed circulation, as much as $56m^2$ of cultivation area is needed per one habitant, and in a 95%-closed circulation the cultivation area size is reduced by almost a half of it, as it requires only $30m^2$. Also, the level of energy consumption for the former situation is higher, almost twice of that for the latter situation. It should be noted here that in Bios-3 simulation cultivation has been lit intensely. As a large area of cultivation is needed, the usage of space was risen to the maximum level, so the paths for people were very tight to maximize space for plants in phytotrons. Despite of the fact that only 1/5 of the needed food production has been gained in Bios-3 simulation, the cultivation area was twice as big as the habitat's area, and to ensure closed atmosphere circulation—three times bigger than habitat's area (for plants and algae). The area should be much bigger in case bionauts would rise animals. Salisbury and others (1997) say that only several to a dozen or so percentage of forage for animals is made into edible meat, e.g. veal and beef only 2,3- 2,9%, and in case of turkey meat—almost 19%. At the same time animals need to be taken care of in a purpose-designed habitat. Salisbury and others conclude that even if animal food production would rise here up to 20%, it is still easier and cheaper to store that kind of food for long term missions, than to rise animals. Those supplies should be properly prepared and stored, not to be spoiled.



Picture 4.14: Biosphere 2 Complex (Global Ecotechnics)

Picture 4.15: Biosphere 2 Architects : M. Augustine and P. Hawes (Global Ecotechnics)

Table 4.1: The area of artificial ecosystems in Biosphere 2 (Global Ecotechnics)

Element of the Complex	m^2	Kind of building
habitat	1000	the main building
agriculture	2000	the covered greenhouse
rain forest	2000	the big pyramid
Savannah and ocean	2500	the streamlined building
desert	1400	the small pyramid
biosphere's lungs	3600	two domes

There is a possibility of multiplication of some bacteria dangerous for the ecosystem and people, so phytotrons have been lit with ultraviolet light, and bionauts had to wear safe masks to work with the plants.

Because Bios-3 construction has been made from welded stainless sheet metal, during the experiment some of elements from the welding have seeped to the cultivated plants, e.g. the lead, nickel, aluminum and chromium thickening was 10-20 times larger in plants, than usually. Pewter and titanium were also discovered in plants, however their thickening did not rise to the level dangerous for people.

Bios-3 is the first completely closed artificial ecosystem where people could live, keeping in good health and fit, for a relatively long time which is the greatest achievement of Russian experiments. Considered as a great success is maintaining the right water and gas condition with a help of green plants, ensuring fresh food for people at the same time.

Biosphere 2 is a large complex (Pict.4.14), it covers 1.25 ha, built in the USA, on Utah desert, to research artificial ecosystems in an isolated environment, that has been designed by Margret Augustine i Phil Hawes (Pict. 4.15). Most of the buildings are made from glass and steel, and they contain a habitat, cultivation area and some other ecosystems (Tab. 4.1).

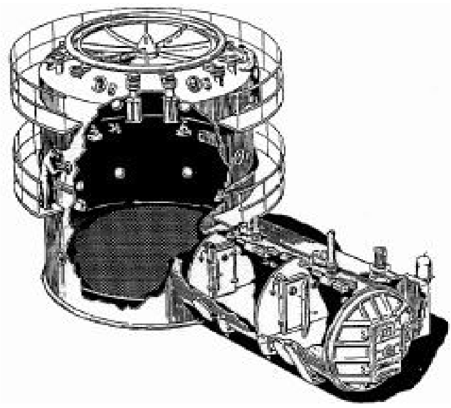
Picture 4.16: A kitchen in Biosphere 2 (Global Ecotechnics)

Picture 4.17: A library in the bios (Global Ecotechnics)

There were simulated air and water circulation, vegetation and proliferation of about 3800 plants and animals species in artificial ecosystems environment (Salisbury and others 1997). There were also two experiments conducted with human participants in Biosphere 2, 1991-94. The first one lasted for 2 years, the second one 6 months. Both of the experiments are a good source of information about artificial ecosystems with human participation, however, none of them succeeded fully: a lot of plant species and animals died, and supplying air was required (Salisbury and others 1997). In the first experiment 8 people took part (4 men and 4 women), they lived and worked for two years in the closed, multi-ecosystem complex. Some of the insides are shown in Pictures 4.16 and 4.17. Almost 45% of the time habitants had to spend on the 0.2 ha cultivation area taking care of animals and working on food preparation. During the second year of the experiment some more effective methods of cultivation were introduced, so the crew could spend less time doing so.

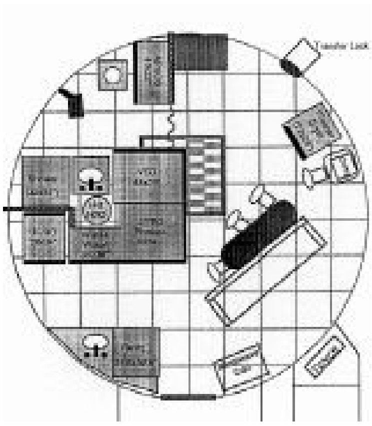
The results of Biosphere 2 experiment are published by Silverstone and Nelson (1996). As it is stated there, rice, sweet potatoes and bananas are observed to produce the largest amount of food. Fresh vegetables had their place in everyday diet. Hens laid few eggs only because their forage was poor. Goats had been less problematic, they gave a lot of milk and bred 6 yeanlings. The fish had been also grown. Altogether the whole grown and risen food had been enough for 8-10 people, and it covered about 80% of food required for the bionauts, and the rest had come from supplies. Because of the vegetarian diet, bionauts' level of cholesterol came down a lot what had a positive effect on their health and mood. Two people resigned from having meat when it became accessible, they got used so much to eating vegetarian food. Thanks to diversified ecosystems in the complex people had access to more diversified diet (comparatively to Bios-3).

In the said complex, the steel construction propped glass panels. The high tropical trees required a high building, so the construction there was 23m high. The ocean was over 8m deep. For better simulation of a natural environment some mechanical solutions were introduced, e.g. a sophisticated device created waves in the ocean, another one pumped stream-water, another one was responsible for rain. However, many species got extinct there, and only a few accepted the artificial environment, what proves that most of the natural mechanisms are still unknown for people, and that it is very difficult to create an artificial ecosystem, which would work properly. Glass construction allowed a lot of sunlight to reach the insides so at the beginning it was the only source of light, but there was still only 50-60% of sun light that could get through the glass. Additionally, the sky was covered with clouds often during the experiment, so the artificial light had to came in use, what helped to gain larger harvest. Some fertilizer was used, one that would not influence food badly and people's health that way. However, it caused a large amount of bacteria, which used much of the oxygen from the atmosphere. The construction turned out not to be air-tight enough, so the leaks of gas rose up to 10% during one year. Thus, supplying oxygen was needed twice during the first experiment (Salisbury and others 1997).



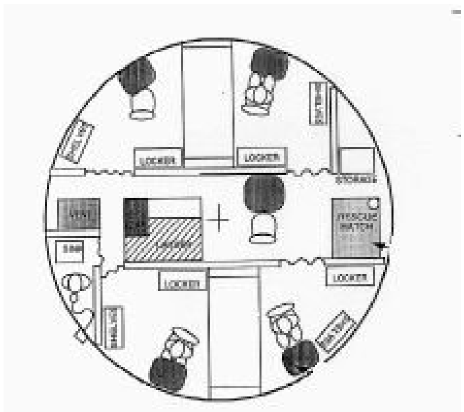
Picture 4.18: Bios outline LMLSTP (JSC NASA)

Picture 4.19: Habitat module from the outside (JSC NASA)



Picture 4.20: Floor plan of the first storey

(JSC NASA)



Picture 4.21: Floor plan of the third storey

(JSC NASA)

During Biosphere's 2 simulation the fact that people could produce food to feed themselves is considered as a great success, and they had to depend only little on stored food. Such a large complex was built for the first time then, and the designed instruments to maintain artificial climate worked properly for different ecosystems. Bionauts who took part in the experiment did not suffer illnesses, and what is more, their health got better thanks to the vegetarian diet.

On the grounds of analyses of the simulation effects conducted in Biosphere 2, a group of scientists designed BIO LSS for Martian mission (Silverstone and others 2003). They chose the plant species which performed best in the experiments, and those of the highest calories amount (the vegetarian diet caused some lost of weight of bionauts).

LMLSTP is an abbreviation of Lunar–Mars–Life-Support Test Project. The four life support simulations of life, supporting bioregeneration systems, were named by this name for the manned missions to the Moon and Mars, conducted in Johnson Space Center, which is a part of NASA, where manned missions to the Space are researched[8]. The goal was to simulate ALSS (*Advanced Life Support System*), the BIO LSS by NASA. The simulation consisted of four experiments, called: Ist Stage, IInd Stage, IInd A Stage and IIIrd Stage. In August 1995 the first experiment took place. One man spent 15 days in an air-tight simulation chamber, divided into two: a habitat and an agriculture area. The test proved that bioregeneration of air may be supported with growing grain for one man—from the sowing time to the harvesting time—in an artificially maintained climate with the help of artificial watering system and high-level intensity of artificial light. Mostly PC LSS were tested during stages II and II A.

During the III Stage it was tested if grain could purify atmosphere (adsorb carbon dioxide) and replenish oxygen for people to breathe. The same grain became the main source of food for people, however not very diversified, because only wheat and lettuce were cultivated. CO_2 exuded as a by-product during faeces processing and was directed to the cultivation chamber. The test took place in the autumn in 1997 and its results were satisfactory. It lasted for 90 days and 4 people took part in it. Two hermetically connected modules were used for the simulation (Pict. 4.18 and 4.19). The first module, a bigger one, was of a shape of a vertical cylinder, 6m in diameter, divided into three floors. The doors on the ground floor lead to the second chamber in shape of a horizontal cylinder. This module was smaller and consisted of

8 www.jsc.nasa.gov

Picture 4.22: The mess (JSC NASA)

Picture 4.23: A private cabin (JSC NASA)

Picture 4.24: The body-building room (JSC NASA)

Picture 4.25: The toilet (JSC NASA)

Picture 4.26: The staircase (JSC NASA)

one floor only. The first one was used as a habitat, the second one was indicated as a cultivation area. The ground floor in the habitat module (Pict.4.20) was divided into three functional rooms: the biggest one was used as a mess and staff-meetings room, there were also cupboards, closets, kitchen equipment, a washing machine and a dryer (Pict. 4.22); the second room was used for body-building (Pict. 4.24). The third small room was used as a toilet (Pict. 4.25).

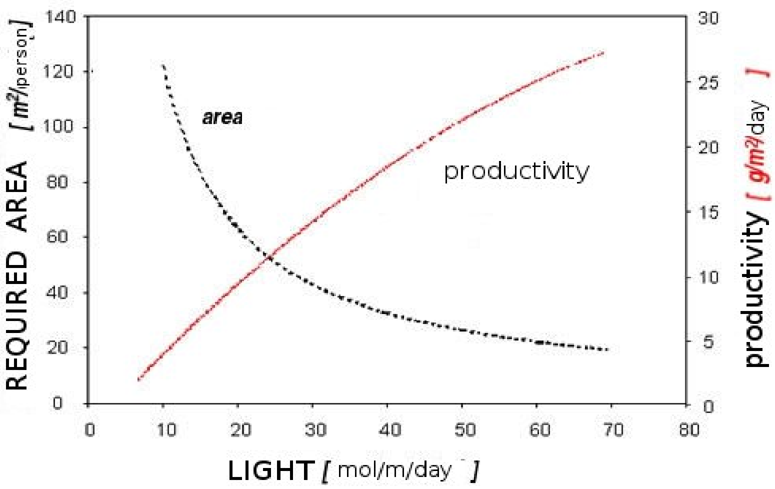
There was the technical room containing all the instruments and testing ALSS devices on the second floor. The third floor (Pict. 4.21) was divided into four small private cabins and a small hygiene room with a washbasin. Everything was put tightly due to minimalistic ergonomic in very small space of the whole bios. Private cabins were very small (Pict. 4.23), and ship-stairs between the floors were rather narrow and dangerous (Pict. 4.26), and especially uncomfortable to walk up and down with carrying anything.

The intensive cultivation tanks were put in the smaller module. Grains were cultivated in a multi-storey fashion: they were arranged on several shelves, one above another one. They were sown in a special way (Pict.4.27). The passages between the shelves were very narrow, to create as much space for agriculture as possible(Pict. 2.28). Lettuce was cultivated in a special machine called '*salad machine*' (Pict. 4.29). Both the chambers were lit with artificial light only. Plants were lit intensely to grow faster. This seems to be the only solution when the agriculture area is limited so much. The graph in the Picture 4.30 shows how the amount of light energy provided for plants could influence their productivity and their area needs. The better the area was lit, the more independence from PC LSS is possible, and the less dependency on stored supplies, and what follows, the less storage space, would be needed.

Picture 4.27: Sowing grain (JSC NASA)

Picture 4.28: Grain cultivation in bios (JSC NASA)

Picture 4.29: „Salad machine" (JSC NASA)



Picture 4.30: Cultivation productivity reliance, to the area size and light intensity

On the grounds of analyses of different life supporting systems based on bioregeneration that have been in use until now, the author worked out some designing clues for BIO LSS:

1. The exploitation of BIO LSS during Martian missions is essential for food production. That is why it is crucial to include elements of the life supporting systems during the designing process.

2. BIO LSS requires cultivation space and, if needed, space for rising animals, too.
   - For security reasons the cultivation space should be separated from the habitat space to prevent harmful micro-organisms, radicals, and insects from penetrating the habitat space.
   - The cultivation space may be designed multi-storey or on one level only.
   - A specific shelter should be designed for specific species (e.g. a goat shed, a hen-house, a hive, a fish tank etc.)
   - To create different and optimal environment and ensure the best possible vegetation for different plants it would be best to divide the cultivation space into specific sections (specific climate, specific light conditions, space etc.).
   - One species grain fields could be divided into smaller pieces to sow grain variably in time to ensure the continuity of harvest, and to ensure also water and atmosphere recycling.
   - Dividing agriculture for separate modules secures them. In case of failure of one of them it is more probable to keep the whole LSS safe and functional.
   - Narrow passages between cultivation fields and multi-storey cultivation makes it possible to use the available space to the maximum. However, at the same time it lowers the passage-comfort for people, that is why farming machines may work better under such conditions.
   - Working together while cultivating plants and preparing food may socialize people better. Agriculture and chambers for preparing food should be comfortable for many people to work together, sharing different jobs.
   - The most effective in production and high calorific fruit is banana. However, its palms are very high and need a high building.
3. The design of agriculture modules is determined by the specific of light conditions.
4. In case of sunlight as the main source of light;
   - agriculture construction should be built as a greenhouse, its covering material should be characterized by high level of light penetration;
   - cultivation is extensive and takes large area on one level;
   - to intensify natural light there might be planned a system of mirrors directing the sunlight inside the module.
5. In case of artificial light as the main source of light:
   - the optimal system of lights should be designed to illuminate the whole cultivation area properly;
   - it enables multi-storey cultivation; the shelves' system and their deployment should be directed by the comfortable access to plants during

harvest, and by the height of plants grown;

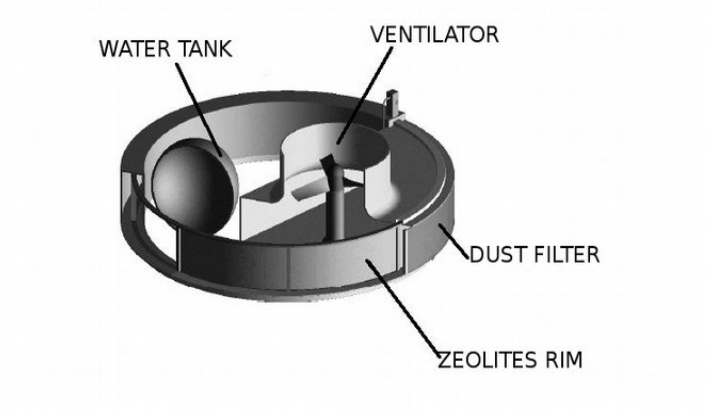
- cultivation might be intensified, plants may grow densely, and the area may be smaller.

6. BIO LSS needs proper storage rooms that should be planned to function well.
7. The agriculture module should contain a separate room to store seeds, bulbs etc. ;
   - there should be planned also some space to store harvest containers and some space for provisional storage of collected food;
   - the main storage could be planned in the agriculture module or in the preparation food module;
   - a tool-shed should be planned close to the entrance, or in the middle of the cultivation area to ensure a comfortable access to the tools;
   - there should be a dressing room with cabinets for protective clothing, face masks, boots overlaps etc. to prevent micro-organisms from penetrating the habitat, and to protect people;
   - the compost storage to collect inedible biomass to make natural fertilizer should be separated to prevent the rest of the base from bad smell, bacteria and mould;
   - waste not suitable for compost should be stored in vicinity of their processing places, e.g. near a furnace.
8. Production and preparation food needs suitable rooms equipped suitably:
   - a room to mill grains and sift flour;
   - a suitably equipped kitchen to bake bread and diversified food preparation (preparation and serving food has a great influence of people's mood).
9. The material assortment for building a base is important. The penetration of elements from building materials into the plants and into the habitants' organisms should be limited to the minimum on the planning level.
10. The detailed plan of the agriculture should be done with the cultivation specialists assistance.

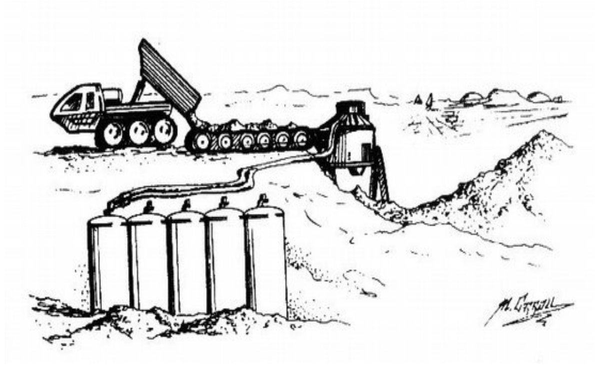
In-Situ Resources Utilization (ISRU): There are the same elements on Mars that are known on Earth, however, in a different amount, and a different chemical and/or mineral form. They might be exploited to support life in the habitat. ISRU LSS is a collection of devices adapted to do the job. They serve the habitat with oxygen supply to breathe, neutral gas for the atmosphere inside, and with drinking, hygiene and economic water. Drysdale and others note (2003) that they work similar to PC LSS, apart from the fact, that PC processes the habitat's material (from the inside environment), but ISRU works with the outside environment (Mars). The inside environment is more predictable so PC seems to be more dependable. However, even the most hermetically closed habitat does not ensure 100% of airtightness.

Additionally, the air loss is higher because of the use of airlocks during EVA. PC should complete such shortages exploiting reserves from Earth. The more often people would go out, the sooner reserves would end.

The amount of compressed gas, taken for the atmosphere in the habitat, is one of the survival problem. The longer the mission, the larger amount of gas should be taken. However, there should not be to much load transported so as not to overload the spacecraft. Devices for utilization of local sources to complete the life supporting system might be sent earlier, before people could go to Mars, and they could start collecting those resources in advance (Zubrin and Wagner 1997). Such a solution lowers the risk of mission failure and allows taking smaller amount of LSS reserves from Earth. The instruments sent once may serve any mission to Mars. ISRU exploitation expands self-sufficiency of the base, and its independence from supplies from Earth. This system allows collecting not only oxygen to breathe for people, but some neutral gas—nitrogen, argon—as well, what makes the whole mission project more economical. The atmosphere of Mars is well known today. There have been many researches conducted in different parts of the Red Planet which proved its atmosphere chemistry, which is similar in all the regions of Mars. Atmosphere consists of carbon dioxide mostly (which is a good source of oxygen), nitrogen and argon, and there were found traces of water vapor as well. The detailed percentage of gas share in Martian air is well known. Thanks to this knowledge the IRSU apparatus may be planned in details to process atmosphere up to the needs of LSS. Zubrin and Wagner (1997) write that, despite of Martian atmosphere being very dry, it is still possible to collect water from it. Zeolites—micro-porous, aluminosilicate minerals—are strong water adsorbents. They can adsorb water vapor incredibly efficiently, and they leave only several elements of it per milliard in the atmosphere around. It is a much lower value than for the average humidity of Martian air. After the adsorption process is finished, it is possible to heat zeolites to obtain water. Dried zeolites are ready to process repeatedly. A project of an instrument equipped with zeolites to adsorb water vapor from Martian atmosphere has been introduced by Grover and others in the project WAVAR (Grover and others 1998),*Water Vapor Adsorption Reactor,* a reactor to collect water from water vapor. WAVAR is equipped in a spherical tank to collect water after its condensation. The whole apparatus is 1 m high and 8 m wide. It is going to be installed ultimately in Martian module according to NASA Model Mission (Pict. 4.31).



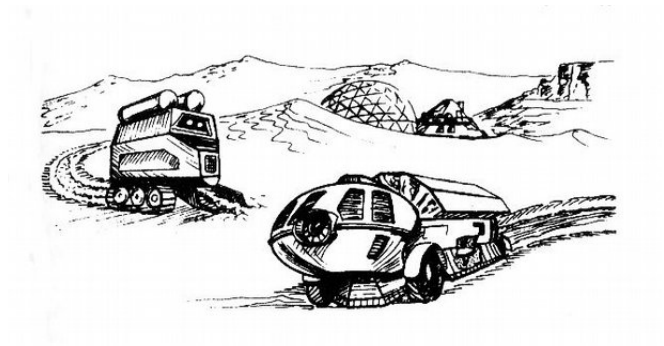
Picture 4.31: WAVAR to collect water vapor from Martian atmosphere (Grover and others 1998)



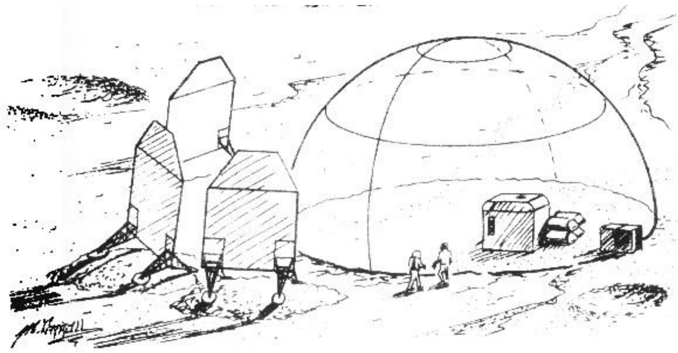
Picture 4.32: Furnace to collect water from the soil supplied with dump trucks; waste is thrown away on heaps (Michael Carroll)

There is enough water on Mars (section 3.1), so it is worth exploiting IRSU apparatus there, instead of taking water from Earth. Water collected with IRSU could be used as drinking, economical and hygiene water. It is also possible to obtain oxygen from water.

According to the method of exploiting water in regard of its state it is possible to use different machines to collect and process it (depuration, heating etc.). Hard ice might be cut into blocks for transportation; surface hoarfrost could be filtered from dust and sucked into a tank. To obtain water from the surface, regolith should be heated to vaporise water, next the vapor should be condensed into adequate tanks. If water is found deep underground there should be gushers made to reach it through the dry layer. Several methods of obtaining water are shown by Zubrin and Wagner (1997. p.254). They note that to vaporise soil water it is crucial first to heat it. There are two methods of doing so: to supply soil to the heater, or supply heater to the ground. In the first case the dump truck should be used for taking and transporting gravel to the furnace (Pict. 4.32). The regolith would be heated there until water vapor would be obtained. After condensation it would be stored in a separate tank, and dried regolith would be removed to store in heaps nearby. In the second case Zubrin and Wagner (1997) suggest several other solutions. For example, a vehicle equipped with a microwave emitter would heat the ground in front of the vehicle. Water vapor would condensate on a canopy in the back of a vehicle (Pict. 4.33). The advantage of this solution is that there is no need to dig in the ground, so there is no need to provide any heavy vehicles. However, this solution characterizes with high-level of energy consumption.



Picture 4.33: Left: mobile furnace; right: vehicle equipped with microwave emitter (Michael Carroll)



Picture 4.34: Mobile greenhouse with mirrors (Michael Carroll)

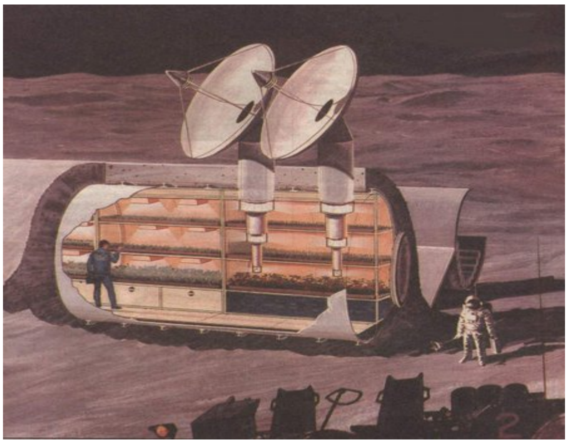
They also suggest to use a mobile furnace on a wheeled vehicle to collect regolith from the surface. The regolith would be baked in the furnace and after water evaporation it would be thrown away behind the vehicle[9]. The natural greenhouse-effect would be exploited there to evaporate water from the regolith, what would lower significantly the energy consumption. A vapor-proof, transparent dome would be put up on a chosen piece of ground (Pict. 4.34). The insides of it would be heated additionally with mirrors following the sunlight, fitted next to the dome, beaming the light inside. Heated ground would ooze water vapor which would build-up as hoarfrost on the cold tile. Frozen water would be stored in a freezer on the side of a dome. Zubrin and Wagner counted that this solution would ensure high efficiency in water production saving exceptional amount of energy at the same time.

One of local reserves on Mars is the sunlight. It might be exploited with sun-batteries for energy production. However, they should characterize with high efficiency level, otherwise, there should be lots of them to meet the needs of all the instruments in base. Sunlight would be concentrated in beams with large mirrors, and directed inside with light tunnels. Such a beam of light would be suitable to heat cultivation area and the habitat. Lockheed company suggested that idea, it is shown in Picture 4.35.

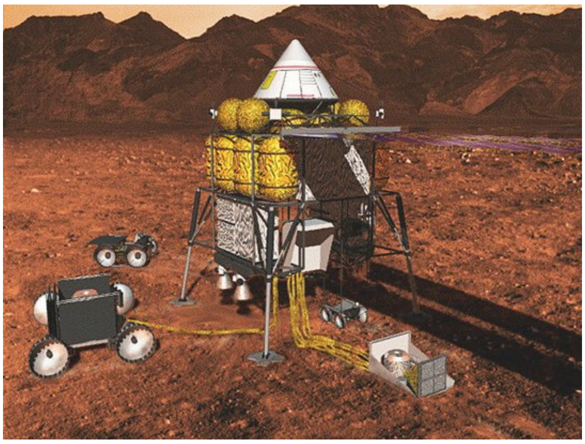
According to the NASA DRM there should be fuel production from local resources on Mars as well. ISRU devices would do the job (Pict. 4.36). Oxygen and water would be made as by-products of such processing; they would support LSS.

Drysdale and others note (2003) that ISRU may cooperate with other systems. When physic-chemical processes are responsible for air recycling in the habitat, ISRU might be exploited only for complementing loss of gas caused mainly by the use of air locks. Utilization of local resources may support BIO LSS with carbon dioxide supplies for plants to breathe, Martian soil for cultivation, and water for plants.

9 The idea is taken from B. Clark, A day in the Life of Mars Base 1, *Journal of British Interplanetary Society*, 11.1990



Picture 4.35: Illumination of cultivation area according to Lockheed company



Picture 4.36: Fuel production on Mars according to DRM (NASA)

The author notes that IRSU instruments may be multi-functional. For example, IRSU responsible for collecting underground water could at the same time be used to excavate further underground habitats, to mine regolith to build a base safe from the Space radiation (Cosmic Rays) barriers, and to exploit mineral sources. Sanders (2005) lists different technologies of utilization of local resources, which may be coordinated with each other during performing different tasks. He also notes that one device might exploit several different technologies, and it would lower costs of sending machines to Mars.

With some help of machines for utilization of local resources on Mars there might be also obtained nuclear fuel for reactors generating energy, which is also needed by artificial life supporting systems.

PC LSS devices might be very small, and BIO LSS consumes small amount of energy only. At the same time, utilization of local resources needs large and heavy machines that consume much energy, where there are different vehicles exploited. However, thanks to IRSU LSS Martian base may be self-sufficient for a very long time. If, in any case, water or oxygen were lost, PC LSS should exploit stored goods from Earth, or even an immediate supplying them from Earth would be required. However, thanks to IRSU, lost supplies may be complemented almost at once *in situ*, what is a great safety assurance provided with IRSU. Utilization of local resources is also a very economic solution because while processing them to obtain one product, it is common that some others products and row materials are obtained as well. For example, during processing local resources to obtain oxygen from carbon dioxide in the atmosphere, carbon is produced, which connected with hydrogen gives fuel. What is more, once sent IRSU may serve crews of many missions and be exploited for a long time for Martian base.

On the basis of analyses of utilization process of local resources on Mars described in the dissertation the author gives architectonic clues for ISRU LSS:

1. There are garages and workshops for ISRU vehicles required at a base.

2. Machines for collecting water vapor from Martian atmosphere connected with zeolites exploitation should be fitted in the shape and size of a habitat (e.g. as it is shown in the project WAVAR for DRM module). There should be pointed out a place to fit such apparatus at the base, taking into consideration that is should be a place where air flow is not obstructed.
3. There might be cooperation of different ISRU instruments obtaining sunlight taken into consideration in the base project, e.g. mirrors and light tunnels.
4. There should be planned in advance storage space and water tanks for collected products.
5. ISRU instruments to collect Martian regolith and supplying it to agriculture module should be built in vicinity; there might be suggested solution of its connection with the base construction (Kozicki, 2004).

General tips for LSS in Martian base:

On the basis on analyses of different life supporting systems, the author lists general clues to introduce them to Martian base:

1. To support life on Martian base LSS is crucial.
2. For a long-term safe stay of people on Mars a large habitat is required. A Space-suit, an mpv vehicle or a shelter are temporary solutions only to support life.
3. Independent from the size of a habitat, it is crucial to assure complete LSS:
   - larger habitat needs just more productive equipment;
   - LSS cost per unit of habitat space is lower for a larger habitat.
4. The architect should have basic information about LSS to design Martian base properly, because those systems influence the architecture.
5. Different kinds of resources to support life need different base design:
   - stored goods need large storage space;
   - physic-chemical regeneration needs comparatively small equipment which should be built inside Martian base in an appropriate configuration;
   - bioregeneration needs agriculture modules and appropriate equipment which should be installed in those modules;
   - utilization of local resources needs equipment which should be installed outside Martian base, but it should be connected with it properly; ISRU vehicles need garage and workshops space.
6. Long-term mission to Mars needs BIO LSS to assure food supplies for

people.

7. Life supporting system require space to store:
   - oxygen, carbon dioxide and neutral gas;
   - clean drinking water and water for other purposes;
   - food supplies taken from Earth;
   - food produced on Mars;
   - seeds, bulbs etc.;
   - waste water;
   - solid waste;
   - separate tanks for urine and faeces;
   - spare parts for LSS.

4.2 Socio-psychological problems

The key-role of socio-psychological problems during Martian missions

Social psychology is a part of science researches of how other people's presence and their doings may influence the psyche of an individual (*Wikipedia,* 2007). It deals with an individual functioning in social situations, their relationships with other people, and their influence on behavior, attitude, convictions of others. This science focuses on problems of attitude and social views shaping; it conducts researches on the specifics of getting to know people, and other social objects, as social pathology, social conflicts etc. A psychology of small groups is a part of social psychology; there are researches conducted on inside-groups processes, and on the influence of a group onto its individual members (PWN Encyclopedia). Conducting researches on socio-psychological problems seems here crucial for manned missions to Mars and the exploration of the planet. The conditions, that crew members are put under, are critical for individuals and groups—psychically for individuals, and for the community—socially.

Due to different projects of national Space agencies, first manned missions going to Mars should consist of several people (similar to the missions to the Moon and to orbital stations). In the following part of the dissertation there would be described socio-psychological problems of small and isolated groups of people taking part in missions in extreme conditions on Earth and in Space, such as Mars mission's simulations planned by Space agencies like NASA and ESA. Researches conducted by sociologists and psychologists on small groups of people show a high level of possible socio-psychological risk of failure of people sent to Mars, and the danger of the failure of the whole mission. Sauer and others (1997) note that an individual is able to bear even the most uncomfortable life conditions similar to those at orbital and poles stations, but only for a limited time. The longest time a man, a Russian spaceman—Poljakow, has spent in The Space was about 430 days. It was a difficult and exhausting psychically experience for him. However, a mission to Mars is planned by NASA to take 2,5 years! Kanas says (1998) that socio-psychological problems in case of long-term missions may become a crucial factor for the success, or failure, of such missions, and what is not considered a problem for short missions. There are several reasons to that. Firstly, the mission's objectives and tasks to complete are more complicated and there are more of them, so are the expectations from the crew, and larger responsibilities. Secondly, there are times of increased activity in turns with times of monotony, when occupying time with entertainment may cause stress to some people. Thirdly, any minor misunderstandings or disagreements among the members of the crew, which might be tolerated for a short time, escalate and may become exhausting for people when they last for a long time, and they may generate serious interpersonal problems. Guena and Brunelli (1996) also underlines that keeping psychological health of long term missions crews is the main cause that influences the success or failure of such a mission. There should be exploited every possible opportunity to attenuate stress sources, because in case of such a long-term mission to a distant place it is impossible to stop working, and there are not many possibilities to relax because of limited life-space (Sauer and others 1997). The problem seems crucial, because the success of the first mission determines the world's attitude towards further manned missions to explore Solar System.

Architectonic tools may help to minimize lots of socio-psychological problems. This is proved with many researches conducted on small groups of people in restricted habitats in extreme conditions—so called ICE—*Isolated and Confined Environment*. That way the human aspect becomes the main agent in the process of shaping architecture on Mars.

Physical and social isolation from the outside world and staying in an isolated and confined habitat in extreme conditions would influence greatly morals and behavior of the group. Sociologists say that ignorance towards the importance of the sociological problems is as much dangerous as ignorance towards laws of Physics[10]. Among others, Guena and Brunelli (1996) explain the key role of socio-psychological problems: social and interpersonal interactions play the main role in human life. Members of every society work according to specific rules, schemes that influence their behavior: in a positive way (friendship, love, solidarity), and in a negative way (confrontation, jealousy, hostility). This is the indisputable fact that in small, confined groups, such as a Space mission crew, it is crucial to understand and avoid any negative interpersonal relationships, and to create and develop some positive relationships. Interpersonal tension, if not reduced, may become the main cause of stress; such tension does not disappear in time and it may influence all members. Kanas underlines (1998) that to success properly in the mission's goals it is crucial for the crew to keep good interpersonal relationships and cooperation abilities.

10 '*Durkheim notes in "Suicide" that social forces are as real as cosmic forces, and it is indeed suicide to ignore his observation*' *(1997).*

Among other agents, which may influence badly general human condition of the crew members, stress seems to be the most critical one for psychical and physical well-being, and for work efficiency (Guena and Brunelli 1996).

Examples of analogues of Martian missions

The scientists take into consideration studies of human behavior in situations analogue to Martian missions, while researching the socio-psychological problems of such missions. There have been found many analogues of that type. The author lists them according to their similarity in nature of Martian mission:

a) *Similarity of environment*: there are extreme conditions in the surrounding environment, which human being is not adapted to, or adapted to a limited extent only:

- underwater environment,
- Antarctica and Arctic,
- the Moon surface,
- high mountains area.

b) *Similarity of social isolation environment*: a group of people limited in number, isolated from their everyday environment stays for a long time together, in a habitat of limited space, where communication with the outside world is constricted:

- polar stations,
- polar expeditions,
- high mountains expeditions,
- Space missions,
- simulations of Space missions,
- MARS analogues,
- closed ecosystems experiments,
- underwater habitats.

b) *Similarity of an artificial habitat's environment*: the closest environment is artificial, mechanical, fully equipped with electronic devices, digital machines and robots—instruments that should be exploited, monitored and serviced; at the same time they are the main factor influencing survival of the crew members and the possibility to realize the planned tasks:

- Space missions and Space flights,
- plane missions,
- flight control,
- complicated industrial processing monitoring,

- nuclear submarines,
- simulations of Space missions,
- MARS analogues,
- polar stations (partially).

Mapping out significant similarities that are the basis to prove socio-psychological researches relating to those analogues is considered as creating valuable sources of information in the subject of human behavior in Mars missions. Table 4.2 shows the list of those analogues and degrees of their relationships to Martian mission specified on the basis of analyses made by the author.

Table 4.2: Small isolated groups of people in extreme conditions relationships to Martian mission by analogues, degrees and kind of different enterprises.

	Extreme conditions	Reliance on working properly equipment	Difficult tasks to maintain	Life-threatening environment	Limited supplies and equipment	Isolation from the outside world	Artificial atmosphere conditions in habitat	Outside help is not expected soon	Artificial environment filled with precise instruments	Limited sunlight
Polar terminals	XX	XX		X	X	XX		XX	X	XX
Nuclear submarines	XX	XX	XX	XX	X	XXX		X	XXX	XX
Orbital terminals	XX	XXX	XX	XX	XX	XXX	X	XXX	XXX	
The Moon missions	XX	XXX	XX	XX	XX	XXX	X	XXX	XXX	X
MARS analogues	X	X	X		XX	X			X	
Aviation and industry working environment		XX	XX						XXX	
Underwater habitats	XX	XX		XX		X	X	X	X	
Bios experiments		XX			XX	X	X		X	X
Polar expeditions	XX	XX		X	X	X		XX		X
High mountain expeditions	X	X	X	X	X			X		

Orbital stations: they are small science laboratories for several people, placed on the Earth's orbit. In regards to the specific nature of researches conducted there, and the transportation to those (considered as very expensive, complicated, and dangerous), they are specified for a long term stay for people, to live and work there. One mission can last from several weeks to several months. The group of habitants do not leave the station for the whole mission—the return to Earth is possible in due time only, when the mission ends. The return at the behest of a crew member, or anybody else, is impossible, even in case of failure. Orbital stations are built as hermetically closed metal capsules, offering limited space to live, completely equipped with researching instruments and systems serving the station and supporting life. The station may go round Earth in a variable speed and on different orbits, what is connected with upsetting of natural rhythms and sleep cycles in regard to sunrises and sunsets. There is a high-level of life-threatening aspects. The tasks to maintain are difficult, requesting concentration and precision. Space mission simulations which are conducted on orbital stations are prepared in specifically appointed habitats. The gravity, lower level of health-and-life-threatening aspects, and the possibility of outside help are the only differences.

Apollo Moon Missions: they are Space missions for several or a dozen or so people, when the crew consisting of a few members only, astronauts, men of similar age, reaches the Moon, performs different difficult tasks on the surface, and returns back to Earth. The trip to the Moon in the spacecraft takes about 3 days. There is a capsule laid down on the surface, LM (*Lunar Module*). The living space is limited there to the minimum. The outside environment is impossible to survive, and there is a life supporting system working inside the module. Because of the low gravity people are not able to move around easily. The natural rhythm of life, with sunrises and sunsets is disturbed. The immediate communication with the outside world during the mission is impossible. In case of failure any help is not to be expected.

Martian analogues: they are small science laboratories with some habitable space in there, exploited to simulate Martian missions on Earth in the areas of conditions similar to those on Mars. The habitats are located in uninhabited areas, with limited immediate communication with the outside world. Any exit is possible in Space suits only. There is a group of people expected per experiment consisting of scientists from different countries, volunteers, to stay there for several weeks at a time, performing different difficult tasks.

Aviation and industry working environment: working in aviation is very complicated, and some aspects are similar to those of Space flights there, especially that it is not only taking control of a flight, but monitoring and maintaining different tasks at the same time. The strategy of conduct is crucial, and an individual is under great pressure of responsibility for all of the tasks. Flight missions are relatively short, and they are conducted by several people of the same profession. The complexity of tasks conducted by flight control is less complicated, but still, the responsibility is great; making decisions is of great importance, regarding the complexity of cognitive actions. However, there is no long-term isolation in those cases, this is a common place of work. Monitoring of industrial processing is done mainly by instruments, and the complexity of systems, the whole environment is completely artificial, isolated from the outside world. The characteristics are repetitions of difficult performed tasks. There is a small crew taking great responsibilities.

Underwater habitats: they are science laboratories with some living space, designed for several or a dozen or so people living there at the same time, usually for several weeks. The crew (usually they are scuba-divers and/or scientists of different professions) perform different difficult tasks and have to keep the habitat and the equipment there working. The exits are possible in diving suits only. The whole process of surfacing takes at least several hours, and it is strictly connected with pressure differences between the atmosphere around the habitat and the atmosphere at the surface. The underwater habitat is an artificial environment, equipped with professional instruments, where life conditions are also artificially supported. The outside environment is strange: it is underwater, with limited sunlight. Those habitats offer a small living space, with no room for privacy.

BIOS experiments: they are simulations of self-sufficient, self-supporting, artificially created ecosystems, conducted with the help of people. The crew consists of several people, they are scientists of different professions, volunteers. They perform different researches and take care of cultivation. The habitat space is comparatively small, but the agriculture area may be large. The communication with the outside world is limited because of their stay in an isolated area. The appointed experiment time is from several to a dozen or so months.

Polar expeditions: they are scientific expeditions behind the Arctic / Antarctic Circle, conducted on-sea or on-land. The group may consist of from several to several dozen of people. The expeditions are conducted in extreme conditions in the land of perpetual snow and ice, inhabited by few kinds of animals and some plants only. The expeditions move continuously in the extreme environment, search through the hard to reach places, in dangerous, unfriendly and uninhabited area. People live on their ships and in provisional shelters—tents. Any help from the outside is not to be expected soon. One expedition may take from several months to several years (the longest ones were performed at the onset of this part of science, they were first expeditions, in 19th century). Most of the supplies and the whole equipment is carried along. The psychical and physical strength is crucial to complete successfully such a mission.

High mountain expeditions: they are expeditions into high mountains, where only a limited number of participants are included. They can reach dangerous and strange areas, very often uninhabited. The expedition usually takes from several weeks to several months. Most of the supplies and the whole equipment is carried along; any outside help is difficult to provide to. The high-level risk is connected with health-and-life-threatening conditions. There are difficult tasks to perform. The psychical and physical strength is crucial there to complete successfully such expedition.

An out-of-the-ordinary environment may influence human behavior significantly. Socio-psychological consequences of such a state are different from those known from everyday situations. The not-everyday environment taken here into consideration may function as laboratories—natural or artificial—where there could be found some answers for many socio-psychological questions connected with Martian missions (Suedfeld 1998). Polar expeditions and winter seasons at polar stations are considered as the best Mars analogues and Mars exploration analogues (Dudley-Rowley and others 2004, Palinkas 1989, Suedfeld 1998).

The stress origins

Mission to Mars connected with its exploration and provisional living there is a highly stressful situation. The members of the crew would be exposed to different negative stimuli. The author divided here stress origins into: connected with an outside environment, connected with an inside environment (habitat), social, and psychological.

The stress origins connected with outside environment

The main source of stress during Martian missions would be without question the constant health-and-life threat connected with staying in completely strange and unfriendly environment which humans are not adapted to. This situation would continue ceaselessly during walks on the surface of the planet (Dudley-Rowley, 1997). The sense of danger, health and life threat, would increase when the first accident happens and more are anticipated. The fear may become crippling. In that case walking out of the habitat would become impossible without a suit and a breathing device. The suit would protect the human body from chilling, and their skin from being scratched and hurt, and from dust as well. The breathing device would be crucial, because Martian atmosphere is very thin and almost without oxygen. If any of those devices fail, an individual, to whom it belongs, would not leave the habitat any more, until the end of mission. What is more, any damages are not difficult to occur: micro-particles of dust may reach easily any places of connection, and stay there, impossible to remove from there, making it impossible to clean such a place, and to obturate it once again. The suit may rub off or tear on hard and sharp rocks that are scattered around the whole planet. Dust would be especially dangerous during dust storms, when its masses would speed in atmosphere and rub on everything on the way. This kind of danger people could minimize with avoiding walks during dust storms, or moving around outside taking precautions afore-hand. However, constant experience of low gravitation is unavoidable (Allen and others 2003). The gravitation speed on Mars, weaker than on Earth, would make it difficult to walk there. Walking on the surface would be tiring and exhausting, making falling down easy. There are several kinds of problems it may cause, and they may be watched on films shot during the Moon missions[11].

Atmosphere on Mars may stop, however insufficiently, some of highly energized particles from the Space and from the Sun. The radiation exposure, which can cause cancer and destroy body cells, would be another source of stress (Allen and others 2003). A lower sunlight exposure on Mars may be another source of stress there, where distance from the Sun is 1,5 AU and only half of visible sunlight reaches Mars. The author here notes that cloudy sky in autumn and lower sunlight in winter are considered as main agents of depression on Earth. A strange view may cause distress and sense of strangeness: Martian horizon is closer, shades are bluish, rocks and sky are reddish, and the Sun seems smaller.

The stress origins connected with inside environment (habitat)

The inside environment, the habitat, as the author here notes, may be a stressful factor. The general climate inside, its equipment, etc., all those factors may influence the emotional reception of habitants.

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11 On the Moon and on Mars gravitation is weaker then on Earth, however, on the Moon it is half the lower value than on Mars: 1/6g. Thus, problems with moving around on Mars should be less severe than on the natural Earth's satellite.

The author notes here that even the division between an outside and inside environment may become a stress source, which is imposed with a visible and tangible line between two zones: life-threatening and considerably safe. The impression of imprisoning in the habitat may cause mutiny. Restricted rules of limitation of leaving the habitat may cause frustration. A sense of being closed and lack of life space in a tight habitat is one of the main stress origins during Martian missions, especially when they are planned to last very long (Kass and others 1995).

The inside environment of Space habitat is artificial. Equipment for life supporting systems have to work continuously to supply fresh, oxidized air and fresh, drinkable water. Additional systems are responsible for the efficiency work of LSS. Roots of stress may cause sense of dependency on the efficient work of those systems because their failure may lead to the habitants' death (Dudley-Rowley and others 2004, Kass and others 1995).

The habitat is also fully equipped with different kinds of machines and researching instruments appointed to Mars exploration, moving around on its surface, to service the equipment, to communicate with Earth, to obtain fuel etc. The author points that the smaller habitat is, the more space is occupied with those equipment. Humans are surrounded with computers, instruments and robots. It is hard to find a cozy, homely atmosphere in such insides. However, the costs of sending 1kg of any mass to Mars is very high, so people would not be allowed to take many things there, and event without any mention none of unnecessary things, decorative only, souvenirs, knick-knacks etc. The sense of strangeness and discomfort of a place that is to become their home for a long time might become another stress source. The monotonous space arrangement and lack of possibilities to influence its look, changing it may become especially uncomfortable, as this is what people usually do at home. Habitats in extreme conditions are usually treated as shelters and this is the main cause of the lack of taking care of the insides. Most of the times they are rough, monochromatic, inflexible (Suedfeld, 1998), and its individualization is impossible. Continuity, monotony of environment, where people have to spend most of their time, especially if its look is artificial, unpleasant, supplying people with not much stimuli, it may become also a stress source (Palinkas, 1989).

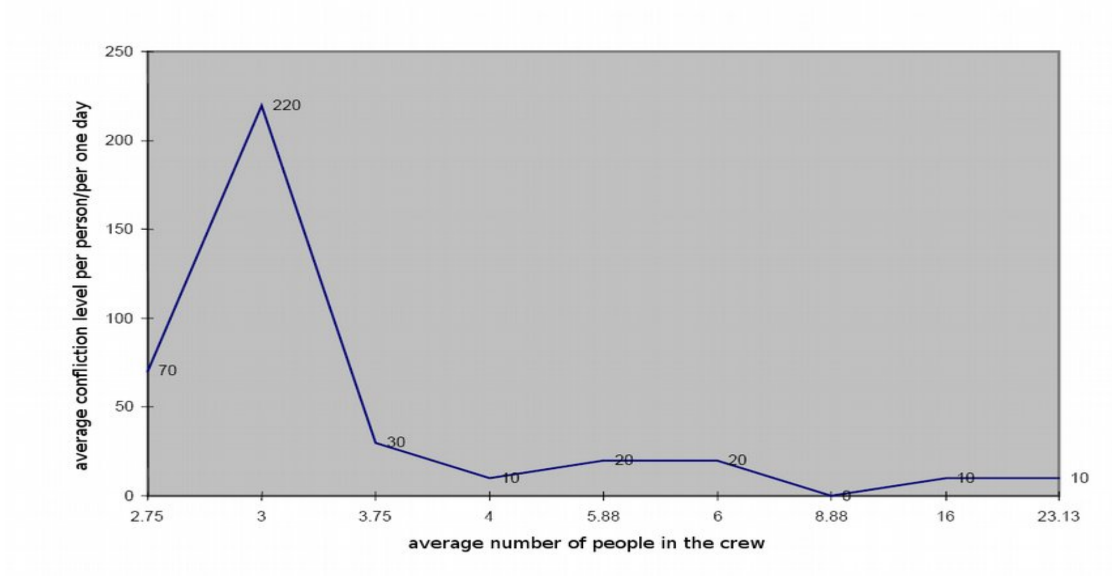
First Space bases were usually small habitats functioning at the same time as working and residential places. Mobility and comfort of habitants were considerably limited by equipment and installations. There was lack of privacy and they were tight for space. Their construction limitations did not allow to install any more windows than absolutely necessary, and they were very small. Considering habitats' small size, it was impossible to provide people with relaxation rooms. For short term missions it was acceptable. However, depriving people of diversified occupations for a long time may become a stress source (Dudley-Rowley, 1997). An individual has to relax and should have some choice ho to spend their free time, to be able to regenerate their strength and minds well and be able to work efficiently. Otherwise, their efficiency drops down, what may cause unsatisfactory accomplishment of entrusted job, and this may lead to the failure of the whole mission.

Minimalistic ergonomic of the insides and noise of instruments continuously working are the main factors of a discomfort sense of habitants in extreme conditions. To design habitable Space modules NASA has created special standards (MSIS, 1995). There are marked the minimal measurements of halls, airlocks and rooms. It provides people with the minimum of space, but not with any comfort to move around freely and with a sense of safe space around. In standard Earth's architectonic projects such strict limitations are not allowed. The ergonomic standards of designing space take into consideration psychical comfort and individual's well-being apart of their physical possibilities.

The isolation of habitats in extreme conditions from the outside world imposes limitation of food, water and energy consumption. There is also created an obligation to depend on the inside recycling system, where no losses are allowed. Such strong restrictions and deprivation of basic creature comforts (e.g. having favorite food or long baths) in a long time may lead to a strong sense of discomfort (Sauer and others 1997).

Origins of the social stress

The polar stations and Space missions, and their simulations, are given as the best examples of Martian missions analogues. It is anticipated that to the first Martian missions would be send small, tight habitats occupied with a few people only. The socio-psychological risks of the scenario is described below. Some of that kind stress origins may be even applied not only to small groups that live in such a specific isolation. However, as science researches prove, the more crew members, the less stressful is the said situation (what is more, they may become inspirational).



Picture 4.37: Conflict reliance to the number of members of in an isolated group (Dudley-Rowley and others 2004)

Dudley-Rowley and others (2004) have analyzed many different Martian mission analogues—including Space missions, the Moon missions, polar expeditions etc. On the grounds of those researches scientists have created the graph showing the reliance of conflict in an isolated group to the number of members of the crew (Pict. 4.37). The graph shows that the biggest number of socio-psychological problems applies to a three-members crew. The ability to conflict goes down along with the rise of the number of members in a group. NASA plans to send to Mars a group of 5-6 people. Due to the chart the ability to conflict is significantly smaller then in case of smaller groups, but at least twice as high as for larger groups. On the basis of researches on analogues conducted by Dudley-Rowley and others it is seen that the minimum of conflicts is observed in the groups of 9 people, and that their intensity is significantly lower than in case of more numerous groups of people. However, it should be noted here that scientists have chosen some missions only, similar to Martian one, so the number of crew members (9) might be characteristic for just those examples. It is safer to say that 9 is a minimum number of crew members to prepare a successful Martian mission to explore the Red Planet. Those conclusions the author notes on the basis of the said science document; to define them better there should be done more researches on a wider division of Martian analogues, because high level of conflicts occurs mainly in Space missions, where there has been a few members only, and larger groups are characteristic for Earth's analogues. Only International Space Station enables organizing groups of seven, or more, members; larger groups have not been sent to the Space yet, so there cannot be said anything definite about the level of conflicts in such groups.

The stress of social origins may be divided as a result of: social isolation, inside-groups conditioning, and environmental limitations of social repercussions.

Social isolation: habitants of Martian base would establish a group isolated from the rest of the world and from other people. The huge distance (from 0.5 AU to 2.5 AU) would separate them from Earth. A long term and oppressive interplanetary transportation would cut out straight communication with relatives, and from visiting associates. The distance would impose a delay in satellite communication. A phone call would be rather impossible because the delay would be 40 minutes long, what leaves only electronic mailing rational there.

Those habitants would create an exceptional micro-society. It would be exceptional because of its almost total isolation from the outside world, starting with isolation of the smallest scale from individuals important for human life (partner, family, friends), through a middle scale—isolation from their social groups (work environment, groups, associations, neighborhood), to the global scale—isolation from people on Earth.

The separation from the loved ones is connected with the lack of spiritual supporting, which is received from relatives and friends in a natural way (Dudley-Rowley, 1997). During a crisis situation—when there are no such people nearby—an individual is left alone, with none to trust to and count on, while searching for some consolation. Suedfeld writes (1998) that possibilities of social support from loved ones is the main way to overcome stress. Deprivation of loved ones, best known people, with whom the psychical relaxation, enjoying life, sense of safety and sense of importance for people is possible, may make it impossible to abide with others (Palinkas 1989). Deprivation people of sexual relationships in long-term partnerships is a particular consequence[12].

The knowledge of social environment people stay in, roles they play, reliance and hierarchy in there gives people a sense of life situations predictability. Every day people keep around those who they know best, those whose behavior seems predictable. Their knowledge grows slowly in time, what gives sense of safety because they know and understand what is going around. Many sociological researches prove a sense of predictability and control of situation is an important anti-stress buffer. Suedfeld (1998) points that at polar stations people from different societies meet, strange to each other; this is a stressful situation when they have to get used to each other, get to know each other and establish their social position in the group, gain some respect, and find themselves in the group hierarchy. Only after some time the social situation inside a group becomes clarified, people integrate with each other and a micro-society is established with common rules and standards. During Martian mission, which is an exceptional challenge for a socialized individual, the process may become turbulent. Currently there are trainings and integration meetings performed for people who could be sent together to a Space station. Those positive activities has begun right after sociologists and psychologists had started the alarm.

Among others, there is one important problem: a group of people participating in a mission is constant and invariable. People are sentenced to live in an artificially established group and there is no escape from there (Sauer and others 1997). In natural social environment people can make choices how to spend their free time—whether spend more time with work colleagues, or to stay with friends or family (Suedfeld 1998). During a mission colleagues and people they have to spend their time are the same people (Sauer and others 1997), and communication with relatives is impossible. Invariability of the situation, repetitive contacts with the same people, lack of relaxation and separation time from the same group of people is a great psychical burden for an individual. Social isolation makes people to learn how to live in an artificially created micro-society, trusting each other, a so-called *forced socialization* (Guena and Brunelli 1996). It is not uncommon that different tasks have to be accomplished together. Private misunderstandings cannot stop it because they are crucial for safety and effectiveness of the mission. Lack of trust, probable rows, sense of antipathy are really irritating then and make work very difficult to perform.

Although habitants of such a base would keep in touch with the outside world, it

12 Kanas (1998) underlines that an important problem during long term the Space missions are sexual relations. He makes reservations that such a long sexual abstinence may be taken into consideration, but not for such a long time. This is why it should be indicated here that may be it would be reasonable to send marriages or long term man-woman partnerships as members of future missions. This, according to him, would minimize the stress caused by the sexual abstinence, conflicts and competitiveness inside a group. At the same time he agrees that there would be no assurance whether that solution may occur unstable because it could lead to arguments among partners, jealousy rows etc. as it happens often on Earth.

would be limited to communication with the mission control on Earth, watching films and pictures from Earth, sending e-mails to families, searching through sent-in news. Beside the physical isolation, the psychical alienation seems unavoidable. Every-day problems would be different from those of people on Earth. Marsonauts may feel sense of alienation and lack of understanding on the side of people left on Earth. They may become reluctant to communicate and cooperate with the mission control because of all those reasons, what has become the source of conflicts during Space missions and such simulations. Dudley-Rowley and others underline significance of it, listing 7 main sources of stress: the huge distance from home, probable communication problems with the mission control on Earth and rising autonomy of the group, which cannot count on understanding, and cannot expect any kind of instant help on the side of the mission control.

Inside conditioning of micro-society: There have been sent crews of astronauts for initial Space missions, people of the same education and profession, men from the same country, similar in culture to each other. There is a tendency, however, that seems to be continued that there are more diversified groups created, e.g. for ISS men and women of different job experience are chosen (Kanas1998).

Crew diversity of polar, Space expeditions or simulations of expeditions is shown in the professional literature as one of main social stress factors. The diversity may be visible in nationality, in the languages spoken, professional language, culture and up-bringing, values, places of interest, education, job experience, skills, work motivation, working during mission, age and sex.

Cultural problems shows themselves in small groups, e.g. when given three people, the two of them are form the same country, and the third one is of other nationality. Those two naturally would prefer to spend time together and talk to each other, because communication is just easier for them, and the third person feels isolated (especially, when the third person does not understand their language). It is also difficult to communicate with professional astronautic language, which has its own unique etymology in every language, based on synonyms, acronyms and neologisms which are difficult to understand or guess for people from different countries (Kanas1998). However, the importance of satisfactory human communication has been underlined many times in cases of isolated groups and participants of difficult experiments (Kass and others 1995).

Cultural problems may be more subtle and straightforward, as well. They may grow from difference in sense of privacy and closeness. Arabs, for example, can stand for physical closeness better than Americans, Japanese can stay even closer to each other in tight for space situations, and Greeks sense of privacy is completely different, as they stay close to other people constantly (Kanas 1998).

Sex differences may cause stereotypical and chauvinistic behavior (Kanas 1998), which is unbearable for women; there were noted also cases of sexual assaults. Lack of possibility to escape or avoid the man who does it may be very stressful.

Habitants of such a base may also show different attitudes of job motivation, which is connected with their profession. Scientists perform better in isolated places because they are used to working alone and conducting their researches during polar nights at polar stations, when labor workers suffer more in such conditions in times when they have nothing to do. Their growing frustration may cause an open hostility or even actions to ruin scientific data (Kanas 1998). Thus, it is seen that lack of understanding of somebody's priorities and the work conduct may become also a stress source.

Diversification of crew members is the opportunity to create ruptures in the group e.g. into sub-groups: old and young workers, scientists and labor workers, those, who prefer silence and those, who prefer partying etc. (Johnson and others 1997). Such ruptures may get deeper in time and become a stress source when those groups start to compete with each other.

Environmental limitations of social repercussion: The sense of tightness for place at polar and Space stations, where comfort was limited to minimum and living space was very small, was one of the main stress sources. There were occurrences of claustrophobic problems in dire cases, too. Being shut in a small capsule is one source of stress, but when an individual has to spend there long time with other people, the psychical burden becomes unbearable. Astronaut Walerij Rjumin, who spent at the orbital station Salut six months, wrote in his diary: “What can provoke a man to commit a murder? To barricade two people in a 7 meters long capsule!” (Kass and others 1995). When several people are put together in a small place, their privacy is lost completely, where they do not have any private cabins, or at least acoustically separated rooms. People cannot stay with whomever they want to, or to stay alone when there is no separation into different zones in base and lack of separate rooms. One multi-functional room—as it was the case for Salut, initial Russian Space stations—creates especially stressful environment. Different habits of other group members may become tiring, growing into unbearable in time, e.g. snoring (Kass and others 1995).

Psychological stress sources

Pain, fear, loneliness, work exhaustion and interpersonal communication problems are the basic stress sources on psychological grounds. Martian missions members would deal with them all the time due to different reasons connected with: physical discomfort, Earth left behind, work performed, and social problems.

Physical discomfort: Guena and Brunelli write (1996): 'every physical discomfort is a stress source for an organism'. During Martian mission people would be constantly abide gravitation three times lower than on Earth. It is seen from experience gained during manned Space missions that human organism may react differently to such discomfort. The most difficult is the process of initial adaptation, which takes about 9 days (Sauer and others 1997). Different problems with skeletal system, digestion and blood circulation affirm all the time and may become irritating or even cause some negative changes in human body. It is also difficult to learn how to move around in lower gravitation. Human being is not adapted to such situations, and it is much easier there to fall down, bump into things, become clumsy. There might occur some physiological problems connected e.g. with swallowing food, sweating, using toilet. Organism reactions to such drastically different life conditions may be headaches, stomach-aches, toothaches etc., and sleep disturbances. Those afflictions are very oppressive for humans and they can lead to their stress. Physical discomfort causing stress may be also connected with inconveniences, sense of tightness in the habitat, and lack of small creature comforts people are used to have at home.

Earth left behind: The most serious psychological source of stress, which habitants of Martian base would be exposed to, may be those connected with leaving Earth for a long time. People are used to some things so much that only in extreme conditions they can note that the deprivation of them may cause anxiety. No view of Earth, its green color, water, animals, known cities and countryside may cause stress connected with lack of normality around they got used to.

Leaving Earth is also connected with leaving home and family, leaving views and touch of close and loved everyday things. The one having strong effect stress source would be, almost for sure, home-sickness and lack of loved ones, and even anxiety of their well-being and not knowing what is going on there without them; and also deprivation of spending together happy and difficult moments with loved ones; adding up a sense of malaise, no way of escape and no going back home, and fear that it would stay forever that way (Guena and Brunelli 1996).

There are many different kinds of entertainment here on Earth contemporary, there are many different opportunities to choose among. Everyone can make decisions what to eat, what to do in their free time, what kind of service to choose from. There are for some their favorite kinds of food, meals, restaurants, clubs where some prefer to go to. Martian habitants would not have any of those opportunities. There would be some specified plants cultivated providing healthy food. Meals would be prepared by astronauts. The limited kinds of variable gratifications, like delicious food, sexual relationships, relaxation, holidays, going out etc. may be a source of stress.

Work performed: The work there may become a serious psychological burden. Kass and others (1995) describe situations, which astronauts may find themselves in during Space mission. They show what kinds of tension an individual is exposed to: 'He has very often only some limited time to perform a task, because the same equipment might be needed for somebody else very soon. He has to work effectively, because there has been a lot of effort and money put into sending him to Space, and he has to conduct researches considering ideas and many years of scientific work of other people. If he fails or damage something, he would not obtain data or may cause their loss. A mistake can damage important instruments, including those that take care of life supporting in the base. Making a mistake has also its psychological level—he is observed by his colleagues. His incompetence may be the cause of that that they would not perform their work, and he would lose some his authority—the same as a sportsman who fails his team.'

The second factor causing stress noted as important in professional literature, connected with work, are periods of increased effort in turns with boredom (Guena and Brunelli 1996). On the one hand, members of the crew count on having difficult tasks to perform, where they can show their professionalism and be given credit for; on the other hand, excess of challenge is tiring. Overworking and overwhelming with duties were one of the most important factors causing stress during Russian Space missions (Sauer and others 1997). That is why nowadays mission plans are not overloaded with tasks, especially that there need to be taken into consideration different unpredictable situations. Everyday tasks, performed day by day, routines, may also result in boredom and weariness, and there would be lots of such tasks to perform during Martian mission: systems monitoring, performing similar tasks every day. Lack of work motivation and despondence to repeat their monotonous duties may become stressful (Sauer and others 1997).

Social problems: Interpersonal conflicts may become sources of psychological problems too (Kass and others 1995). There might occur exhaustion or reluctance to unavoidable abiding with somebody else, group cooperation problems, showing antipathy or aggression to others etc. (Kass and others 1995; Dudley-Rowley 1997). Intrinsic conflict between the need to belong to the group and at the same time the urge to stay oneself, stay independent may become problematic too (Palinkas1989).

Reactions to stress

An individual reaction to stress may be different. It depends mostly on the type of stress individual deals with. Guena and Brunelli (1996) distinguish two types of it: the first one is **sudden and acute** stress, and the second one—**chronic stress**. Reaction to acute stress usually is sudden and botched. It is caused usually by sudden situations. Chronic stress shows itself under influence of long-term exposure, when an individual could have enough time and opportunity to evaluate the stressful situation. Such a saturation with intrusive stimuli causes large psychological burden for an individual. It is assisted with hyperactivity or aversion towards performance of some tasks. That kind of stress is based on more complicated and complex grounds than in case of the former one. Any systems' failure, sudden, unpredictable events that may occur during the mission following by those on the planet: some of them may be more stressful then if they happen on Earth, e.g. falling down the stairs and breaking a leg. Immobility of one member of the crew because of his illness disrupts the course of performing tasks which he took part before in and would increase the risk of failure of the whole mission. Therefore, acute stress should not be underestimated, even if in the literature it is treated as less problematic then the latter one. It should be taken into consideration that chronic stress is very dangerous, because an individual is exposed to its sources all the time and it might be difficult to avoid or remove during the mission, e.g. a constant noise of LSS equipment.

Emotional reactions: Sociologically, social reactions assist emotional and psychological reactions. Kanas (1998) lists two main consequences of social behavior of people exposed to stress in isolated conditions: interpersonal disturbances and disruption of group's coherence.

Interpersonal disturbances usually emerges from dissatisfaction of somebody's presence, which is hard to avoid at a small Martian base for most of the day time. Palinkas (1989) gives examples of problems which occurred during an expedition of a Belgium ship to Antarctica in 1898-99; the ship stuck in ice for a long time during polar night. People were not prepared for such situation and not used to live in so difficult conditions, thus, they were exposed to a strong, chronic stress. The members of the crew were exhausted with the same stories being told again and again, communication problems became unbearable because the group was international. People began to get on each other nerves, they were burdened with dissatisfaction, they got angry with each other or became depressive—one of the people died of heart attack caused by terror of the situation.

Kanas (1998) describes a phenomena of a *scapegoating* that often happens during long term missions and analogue expeditions to Mars. That phenomena means cutting off one person, who does not fit to the rest, from the group, especially if such a person spreads ideas that are not popular among others. Such an ostracism causes sense of alienation which is accompanied often by a *long-eye-syndrome*, which is staring into nothingness, far away, connected with insomnia, hyperactivity and even some psychotic syndromes like hearing hallucinations or persecutory delusion; coming back to the group cures those syndromes.

Disrupted group's coherence is caused by an inside-groups diversity. There are sub-groups established in consequence. This is not necessary a problem, as Kanas says (1998), but still, it can lead to a serious break-up in the whole group. For example during one of the polar expeditions a break-up on the basis of nationality occurred. The sub-groups started to exhibit open hostility to other groups, connected with aversion and lack of common understanding. A similar event took place during Biosphere 2 experiment, when a 4-people group divided itself into halves according to the sex. One of the sub-groups did not want to cooperate with the experiment control, considering them an arrogant mob, the second one stayed loyal to the authorities. Any effective cooperation was impossible.

Physical and physiological reactions: Kass and others (1995) list different reactions of an organism to a stress, which are members of the Space crews exposed to. They are: sleeping disorders, bad mood in general, delayed reaction to external stimuli, lower productivity. Lower physical and psychical activity occurs usually at the beginning of a mission and lasts for several days (Sauer and others 1997). It is probably connected with the adaptation period to lower gravity and its influence on physiology (*Space sickness*); they are usually: aches (tooth, head, muscles), tiredness, weakness, sudden or chronic dizziness, nausea and vomiting, diarrhoea, digestion disorders, lower motion coordination, sense of cold or heat, sense of illusion or hallucination, heaviness of head, arrhythmia.

The most oppressive maladies are those most often experienced during Space missions and their simulations; they are sleeping disorders, bad quality of sleeping, lack of a good sleep (Allen and others 2003). Even slight problems with sleep and some distortions of natural day rhythm can lower organism's performance and physical abilities, concentration and work motivation. Sauer and others (1997) add that reaction time is slower as well as making decisions, and number of committed mistakes is higher during routines or extra tasks; there are also registered memory and concentration problems.

Lack of any contact with the outside world during polar nights at polar stations is caused by the absence of the Sun and the sky visible, and any possibility to look out of the window to observe a view around. This is a cause of psychological problems (anxiety, nervousness, depression), and physical as well as physiological. Most of the crews of such missions are exposed to syndrome of winter time. Its symptoms are: sleeping disorders, digestion disorders, muscles and bones pains (Palinkas 1989).

To avoid such problems that occur during those missions, when there were not enough demanding tasks, Russians decided to charge the crew with some extra job to do. They wanted to deal that way with problems of drowsiness at work, lack of motivation due to thinking about loneliness, loss of attention, not recognizing alarming signals etc. It is usually helpful to charge the crew with many responsibilities, which can alert their attention and are the source of satisfaction from the job well done. However, being charged too much, the Russians got more exhausted and frustrated, focusing on the key jobs and neglecting routines. The data was incomplete, people became less flexible during action, and they had problems with divisibility of attention. Long term burden with much stressing tasks can cause loss of motivation to work, and what follows, to making mistakes, e.g. by taking the short-cuts while making decisions (Sauer and others1997). Allen and others (2003) agree that overcharging with work can cause stress, tiredness, distraction, and lack of job motivation.

There are also following in time some characteristic socio-psychological reactions to exposure to different stressful stimuli during a mission or an expedition in extreme conditions connected with long term social isolation. On the grounds of literature about underwater and Antarctic expeditions J.Rohrer distinguishes three steps of shaping the morals of a group during long term missions (Kanas 1998): first, people get anxious, excited with an important and dangerous mission and adaptation to new life conditions; next, the monotony period begins, which characterizes by boredom, depression and restlessness about other members. People often withdraw themselves from spending the time together, they become hostile. At last, the third step occurs at the end of the mission, when almost childish happiness connected with oncoming finish and going back home. The second stage is the most disturbing one because then it is easy to lose the group coherence, which happens after misunderstandings about little things that increase into important problems due to the crew's anxiety and tiredness of difficult to bear isolation problem. For example people become unduly sensitive about intruding their privacy: opportunity to fight may arise from taking somebody's book or pen without asking for.

Socio-psychological and health problems are the important questions of long term polar and Space missions, as Dudley-Rowley writes (1997). They are proved with researches on Russian missions' data; missions had to be shortened because of the psychological state of their crews. There are known also detailed relations of dangerous behavior of crew members during Space and polar missions, e.g. discovery of stored food decremental of the expedition led the commander of the group to grabbing his gun to kill a suspect. There were noted event of unsuitable and very disturbing behavior of people under stress in ICE (Dudley-Rowley 1997):

- 'Ada got depressed and paranoid. She wanted to escape from the base and commit suicide. Under threat and request they tried to calm her down. At last, when she disobeyed to tie her shoes, she was tied to the flag pole until she would do it.'
- 'Norm refused completely washing himself, he had to be forced to do it. He smelled so bad that no one could bear it any more.'
- 'Lovell disconnected his biomedical monitoring and did not want to connect it. He considered it as an intrusion into his privacy.'

Suedfeld (1998) arises an important question. Although, there are extreme conditions at polar stations, conducting work is difficult and often dangerous, but some people want to go back there many times. It is similar about Space simulations or experiments in closed ecosystems, where there are many volunteers. The desire to do the job connected with the life passion leads people to different stressful situations and to ability of taking the risk gladly. This is what should be remembered while analyzing socio-psychological problems: they put long term manned Martian mission into hazardous situations, but do not necessarily lead to lack of success. As it is proved with researches in the increasing amount of literature dealing with psychology of social Space missions shows that the knowledge in this subject is collected and what is shown, gives hope to the making of right choice of crew members and their perfect preparation.

Devices to minimize socio-psychological problems

To minimize socio-psychological problems, which are one of the most important danger factors that may influence the mission success to Mars, as many as possible stress sources should be avoided and their negative influence diminished to the lowest possible level. Their prevention is possible in many ways. In the professional literature it is often underlined how important it is to choose the right crew members and train them together before any mission (Kass and others 1995). Guena and Brunelli (1996) list also some medical treatment to diminish stress.

Without questioning the best way to ease stress during polar and Space missions is to enable communication with families and acquaintances (Kanas 1998). However, radio calls on Mars would be very difficult. A partial remedy to lack of contacts with loved ones may be watching their pictures and keeping souvenirs from them. Photos are light and easy to pack, and at the same time very highly appreciated by members of polar and Space expeditions as sources of easing stress, anxieties and missing the life left behind (Evans and others 1998).

More recommendations to minimize stress sources in the habitat concerns introducing possibilities of diversification of spending free time (Kanas 1988). Evans and others (1998) prove that those habitants of polar stations, who had organized the most diversified entertainment (especially for an individual) suffered less of socio-psychological problems. The most often listed kinds of entertainment were: reading books, watching films, listening to music, taking pictures, looking out of windows, training, playing team games (e.g. darts), organizing occasional parties (Evans and others 1988). Those, who like similar entertainment need a place to spend some time together; watching films or playing together may bring people of the same interests closer and help to integrate a group (Palinkas 1989). Evans and others (1988) note that such places should be next to the communication halls of the highest intensity (or where they cross).

Noise is an important source of stress, especially in Space habitats, so it is crucial to use acoustic barriers. It is indicated that prevention of any negative influence of noises in such habitats onto their habitants is crucial. It is especially important for relaxation places and studios, where people should be able to concentrate.

Watching out of windows is a special kind of entertainment, greatly appreciated at Space satellites. Kanas (1998) gives a citation from a diary by W.Lebiediew where the astronaut admits that during a stressful situation he would find some peace in looking out of the porthole and that helped him to relax. Looking at views far away, watching at large space, different from the artificial surroundings, was a great anti-stress medicine for him. Suedfeld (1998) proved with his experiments that showing slides of broad landscapes playing second best roles of windows with a view had a beneficent influence on the habitants of polar stations. Additionally, he interjects that photos or photograph wallpapers could have positive influence on office workers and on ill people spending a long time in hospitals.

Long term isolation from world in habitats increases the sense of affiliation to the place. People spend most of the time there during a mission and they fell the urge to personalize the place around to be able to equate to it. They have different means to adapt the place to their needs, to establish more comfortable working and relaxation place. This all imprecates to creating of a new quality of life space and more cozy, homely atmosphere, where an individual can calm down. It can happen of course to a limit of physical limitation of the construction of the habitat. Habitats in extreme conditions are very often rather inflexible. The furniture is strictly assembled and is not to move around; there is also only a few pieces of furniture and it is all identical. Researches conducted at Palmer Station on Antarctica prove that incoming workers there chose rooms of flexible space, where there was possible to move furniture around and add up some pieces of it (Evans and others 1988). Members of crews of polar and Space missions and those who take part in artificial biosphere's experiments try to personalize the space around if possible. This applies to private cabins, as well as to common rooms. Their activities are usually: painting walls, hanging on some photos, making exhibitions of their favorite things, decorating rooms temporary to celebrate different events and creating an archive noticeboards (Suedfeld 1998).

Besides things described above, to feel better habitants of isolated habitats and crews of expeditions in extreme conditions add to the list having mouth-watering food and favorite drinks, as well as wearing favorite clothes and organizing costume-plays (Kanas 1998, Suedfeld 1998).

Conclusions for architect

The result of many conducted researches of socio-psychological problems of isolated habitats in extreme conditions is a list of different tips to design such objects to work and live at the same time. There are many valuable clues that might be taken into consideration while designing a Martian base to make it more human-friendly, open for socio-psychological needs of its habitants. The author lists below some of those clues that are given in different publications about socio-psychological problems:

1. Socio-psychological problems of people living in extreme conditions in isolated environment are one of the most important questions while planning Martian mission. Stress and socio-psychological problems of polar and Space missions, and their simulations connected with the question above, have the direct and significant influence on effects and success of those missions. Different kind of deviations and interpersonal conflicts have been many times pointed out. They have been the source of many problems, which importance should not be made light of in case of long-term and highly autonomic Mars mission, where people would practically count on each other and their equipment alone. That is why the author concludes that socio-psychological problems are directly influential on planning Martian mission, especially while choosing the number of members of the crew, and to point out in what way some possible stress sources should be eliminated.
2. A threat to success to Mars exploration mission—such as one by NASA—seems to be due highly to socio-psychological reasons.
3. People taking part in similar to Martian missions were put under great stress that caused several different undesirable behavior, sometimes even causing putting in danger health and life. However, many of those missions succeeded beneficiary. Thanks to the researches conducted by sociologists and psychologists many clues have been collected to make it possible to minimize sources of stress in such situations. More similar analyses and Martian missions simulations would help to obtain more valuable data in

this subject.

4. The higher number of crew members the more possible is to organize a successful Martian mission (Dudley-Rowley and others 2004). As it can be seen in the analyses of different ICE the highest risk level occurs in case of a three-members crew, and a minimum of desirable number is nine participants.
5. Many stress sources working as the ground of socio-psychological problems are avoidable or their intensity may be significantly lower. It may be done *inter alia* by a well planned habitat.
6. Socio-psychological problems have direct influence on the way a Martian base should be designed, mainly by the suggested minimum number of participants of the crew, and by defining sources of stress in the interior design of life environment, a habitat.
7. The author thinks that in regard to socio-psychological problems, the crew of the initial Martian mission should consists of more people than it is being planned today. A group of a dozen or so people should be send in two spaceships. More people would need more spaceships. They should be accommodated in a spacious and comfortable habitat there—a carefully and optimally planned base.

4.3 Comfort and Ergonomic

Comfort definition

Comfort, due to the “Small Polish Language Dictionary”[13] this is the totality of outside conditions ensuring life comfort; connection of well-being and aesthetics with a sense. In an unfriendly Martian environment of a strange planet that definition should be widen, because it becomes comfortable to be able to breathe and wash. This is why comfort, in case of Martian base, has been described by the author as a totality of conditions that enable to survive and to ensure living and working comfort in an artificially created environment. The quality of living, habitability, (Stuster 1986) is connected with all those elements of life environment that influence the way people do things, and quality of their doings. The greater comfort, while doing things, and the more individual's needs are taken into consideration, the higher living standards are. In regards of needs, comfort has been here divided into: physical low, physical high and psychological.

Physical low comfort means ensuring basic human needs only, like: breathing, drinking, eating, moving around, using toilet and cleaning body in the easiest way. It is possible thanks to:

13“Mały słownik języka polskiego” by S. Skorupka, H. Auderska and Z. Lempicka, PWN, Warsaw, 1968

- atmosphere is breathable
- pressure and temperature of atmosphere is tolerable by people
- drinkable water
- food to survive
- water and toiletries to clean body
- minimum life and work space
- enough light to see

Low physical comfort offers the lowest quality of life. It is assured in Martian base where there are conditions created to enable people to survive, and when they are able to move and perform different operations in the place destined for them to use (minimalistic ergonomic).

Physical high comfort is optimal ensuring basic human needs. They are:

- the best tolerated atmosphere for a human being (optimal temperature, pressure, composition, humidity);
- large living space;
- optimal ergonomic and comfortable exploitation;
- good acoustic of rooms;
- optimal light;
- air cleaned from pollutions and not desirable smells;
- good hygiene conditions (e.g. possibility of having a bath).

High physical comfort ensures rather a good habitability. It may be assured in Martian base when it is comfortable to use, and fitting optimally to physiology, size and movements of individuals. High physical comfort is possible only when a large space is possible to exploit, or rather, a larger area per habitant.

Psychological comfort is crucial to ensure realizing higher human needs. Ensuring psychological comfort is when:

- high physical comfort is assured;
- use of colors and illumination is good, a surface texture is well selected;
- details are taken care of;
- homely atmosphere in habitat area;
- functionalism of space is provided and its exploitation is human-friendly;
- separation of functions, especially working space from living space is assured;
- diversity of rooms;
- space sense is assured and possibility to look at broad landscapes;

- possibility to personalize space around is assured.

If physical comfort in a base is assured, than it may be considered as a safe shelter for people, where comfort of exploitation is taken care of. However, only after psychical comfort is assured, we can say that we deal with a human-friendly habitat—a right place to live, that habitants can identify where they can fell at home.

The purpose of assuring comfort in Martian base

There should be, under any conditions, low physical comfort assured. To establish survival conditions is the prime purpose. It is the prime task to maintain in any outer-Earth habitat. Usually, it is limited to taking into consideration this lowest life standards, avoiding any higher necessities while designing Space habitat modules. During short missions it was acceptable. The scarcity of comfort was noticeable strongly, but still people were able to got used to stress it created, while waiting to come back to Earth. In case of Martian mission the high comfort becomes as important as low comfort. It is the result of two things:

1. People are able to tolerate limited life conditions for a short time only (the maximum time is several months).
2. The quality of live and work space influences strongly effects of performance, which is connected with work and relaxation.

There were problems with conflicts among crew members put together in tight for space, lacking privacy, multi-functional place even during short term missions. People there suffered from the constant noise, lack of private life space, etc. It resulted in physiological and psychological disorders. Astronauts' patience was exposed to a very strong trial. There were many different incidents. The longer people were exposed to stay in such environment, isolated physically and psychically, the larger burden it was on their psyche. Mission to Mars would lasts for 2,5 years. A low living standard is a source of great stress. An individual living under constant pressure, in invariable, monotonous environment and suffering discomfort becomes nervous and it is impossible for him to concentrate. This might results straight on the quality of his work. The aims of manned Martian mission may be successful only when people taking part in it would be able to work efficiently. Without taking that into consideration in designing the base it seems impossible. The efficiency of the staff depends on the mission's success. The more success is possible, the more it is worth doing.

Assuring high comfort level in Martian base aims to:

- keeping up good life conditions despite of life-threatening environment;
- positive influence on the habitants mood;
- assuring safety and comfort sense;
- keeping life and work conditions on the desired level;
- prevention of monotonous life environment and its artificiality;
- increasing working and relaxing efficiency.

The basis of comfort and means of assuring it in base

As the Puerto Rico Group writes (1989), 'architecture is a discipline of art, that occupies with creation of environment promoting physical and psychological comfort'; it applies to human needs as well as to their performance. One of the imperatives in the architectonic design is to avoid performing *sick building syndrome.* Dubbink explains (2001) it is a case when a wrongly designed building causes a sense of stress and sickness to its habitants. Usually it deals with the fact that people sometimes cannot bear their surroundings in relation to interior design, light, atmosphere etc. The question applies to Space buildings for people to live in as well.

The Puerto Rico Group (1989) points to the fact that Space missions are considered as science experiments rather, exploiting machines, and people are treated the same, as instruments to perform tasks, being elements of mission rather than like alive creatures with their own needs and preferences. However, in case of manned Space missions people should be considered as the key elements of the mission, and thus, architecture should be applied to them. Human factor should be considered as an imperative for designing manned missions.

Health and good physical an psychical condition of people are the basis for success of manned missions. It should be considered worth investing money in such projects only then, when where there is anticipated a chance to successfully obtained mission's goals in the best of possible ways. Thus, planning manned missions should start with analyzing human factor. One of the initial problems is to solve the question of a habitat. So, there **should be money and effort invested first, among all, for designing and building a comfortable house and work place for the crew. When for the crew are assured optimal work and relax conditions, so their efficiency would be high, then, and only then there is time to plan other elements of the mission. The human factor should be considered as initial point to plan manned missions to Mars.**

This is true that NASA expects taking into consideration human factor to design any Space habitat (Huebner-Moths and others 1993). However, it is limited to the means of execution of low physical comfort. Specialist's standards MSIS STD–3000 has been created to answer the needs of Space orbital designing. There is accepted a minimalistic ergonomic, i.e. the one, which could assure for an individual to move around and reach anything (even if with some discomfort). There is no taking care about moving comfortably around the habitat and using different devices. Pict. 4.38 shows a private cabin at International Space Station. As it can be noticed a man can hardly fit vertically into the place. He can slip into the sleeping bag and can work at his tiny desk. However, the cubature of the room does not allow putting in anything more in fact. It is rather a box, than a private cabin. The comfort question here is treated here rather at a minimum level.

Picture 4.38: Private room at ISS (JSC, NASA)

The author notes that human factor is an inseparable element of everything what people create. That is why it should be crucial there, where environment is strange to human and unfriendly, where human factor is easy to be lost. However, people are the most desirable ones there. The contemporary rules for planning Space habitats are insufficient when applied to Martian base, which is going to be occupied for such a long time, so it is expected to take care of high physical and psychical comfort.

There are in professional literature recognized different subjects connected with the quality of life, where the architecture plays a major or a minor part. The author arranged them together, considering their connections with architectonic designing.

Safety: Dubbink (2001) puts safety of work environment at the first place among other conditions that should be kept into mind when designing an efficient Space habitat. A construction of the building should keep the safety of inside environment against the negative influence of Martian outside environment. The habitable place should be planned to minimize fire danger and to constrict fire spreading inside. Interior elements should be chosen to minimize any possibility of physical hurting of anybody while moving around inside the habitat. A sense of safety would be assured in the planned protection and right choice of interior design.

Air-conditioning: The standards for planning air-conditioning in Space habitats are described in details by Allen and others (2003). Some of information may be interesting for the architect. LSS equipment would work to assure the same temperature in the whole habitat, about 21^{o}C, and humidity, about 50%, independently from participants' physical activity and heat radiation of the equipment. The particular expectations to the air-conditioning are:

a) training room: ventilation devices should be located in such places so as not to let the air from those places to seep to other parts of the base, especially the kitchen and bedrooms should be protected; it is indicated that ventilation should be planned separately for each standpoint in a room so as to ventilate sweat from the whole body and to make it possible for individuals to regulate its strength and direction individually;

b) bedrooms: as private cabins of a smaller size and exploited only for a defined time during a day should be air-conditioned separately, with possibility to make necessary individual adjustments;

c) kitchen and mess: smell should be collected so as not to sweep to other rooms in the base, and to avoid cumulation.

Illumination: The general idea of designing illumination in Space habitats is the same as for Earth's ones: the sunlight is preferred, and white light, if artificial, should imitate the sunlight spectrum (MSIS 1995). Surroundings in natural colors are received best. The subject is described in details in section 5.4.3.

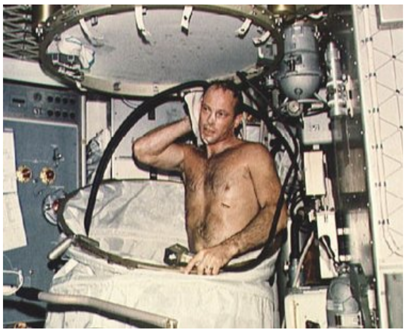
Noise: The LSS equipment would work continuously—24/7—in the habitat, and emitting sound waves. Besides that there would be research equipment working and emitting sound for a specified time. The sources of noise might be loud conversations, music, servicing instruments, work performed in the kitchen, in the training room and the games' room.

The acoustic standards for equipment installed in the Space habitat are restricted by NASA limitations. That is why producers compete to design silent instruments for outer-space missions. However, cumulation of such equipment in a small cubature may have detrimental influence on sound environment there. At the first Space stations and their analogues equipment was neither silent, nor their noise was reduced. As Allen and others (2003) write noise caused partial temporary or permanent loss of hearing to many people. Hundreds of U.S. Navy sub-marines were hurt that way. The United States Government spend millions of dollars to compensate veterans. It was noted that considerably large number of astronauts, who have been working at Mir, experienced temporary hearing problems, and some suffered even permanent loss of hearing, and as a consequence, they were disqualified permanently from participating in future Space missions.

Every vehicle and Space station are equipped with hundreds devices emitting sound waves. A closed space is a kind of an acoustic trap. It results in cumulation of sound waves and their different interferences. In a hermetic habitat acoustic environment of a strong pressure is created. People are made to stay in such conditions almost constantly during the mission (they leave it only for EVA). If the habitable space is designed wrongly, the sound recoils many times from plain surfaces and may create echo effect, standing sound waves, etc. The way of shaping cubature and use of finishing materials should be taken into careful consideration.

NASA worked out much more restricted standards considering the acoustic in a Space habitat than for any other work place, because astronauts spend day-and-night in there, and not eight hours per day only. It should be noted here that those standards have been determined for a four-months mission, because this is the standard time for one crew to spend at ISS. However, the journey to Mars only is going to take 1,5 times of it (six months), and the whole mission 2,5 years, thirty months! That is why the acoustic requirements in Martian habitat should be even more restricted. The noise emitted from some devices can reach up to the auditory perception sometimes (see section 4.1.3). Reducing sound may be accomplished with the use of different isolation material as barriers. It is due to the architect how to plan sound barriers separating rooms to avoid sound cumulation. The use of finish materials also depends on the architectural planning. The most desirable are surfaces absorbing sounds.

As Allen and others (2003) write acoustic comfort is crucial in places where people can relax. Stuster (1986) underlines that it is necessary to minimize noise level mainly in private cabins, for sleeping time, because irritating sounds cause lower efficiency of relaxation of an organism; they make sleeping almost impossible or may even cause insomnia (e.g. astronauts at Skylab complained about noises from toilets next to their sleeping place). Grandjean (1978) writes that it is possible to define periodic change of energy consumption and its recreating or, shorter, between working and relaxation for every alive creature. This change is essential for an organism to live. Depriving one from peaceful relaxsation creates physiological and psychological disturbances. The most important of the habitat's assignment, Grandjean continues, is to assure sleep and relaxation. To make it possible it is crucial to minimize to the greatest extension any stimuli which may activate the animation system. The right means here, besides shelter from too much illumination stimuli, are sound barriers.



Picture 4.39: A shower at the Space station Skylab (NASA)

Picture 4.40: An annex with a sink in a module LMLSTP (JSC NASA)

Hygiene: Stuster (1986) suggests that a lower standard of taking care of oneself hygiene lowers the whole habitat's quality. People fell good when they are clean and tidy. Astronauts at Skylab preferred such a scheme of taking care of hygiene: washing down the body with a sponge every day, and once a week taking shower (Pict. 4.39). Having shower at the Space station was not a comfortable task, because the moisture was collected from their bodies by a cool ventilation, what was connected with the feel of discomfort of a chilled body. On Mars a shower cabin may be similar to the ones on Earth. In the module by LMLSTP program there were in use small compact annexes with build-in sinks, next to the bedrooms. They were not separated with any partition, so they could not assure any privacy. They were put tight between walls, one too close to the next, so they were uncomfortable to use.

Zoning: There was a good design of separation into different zones planned on different levels in many isolated habitats. This is about separation into areas: public and private, light and dark, noisy and silent, work-places and relax-places. As Dubbink (2001) writes, zoning in Martian habitat may help to separate conflicting in functions places for different performances. According to him, life environment should stimulate different social contacts, and discreetly, so as not to burden people with any necessity of bumping into cohabitants, especially when they would like to have some rest or they need to work in silence. There should be created efficient private spaces, especially in the private area: first, second and third levels of it, at the same relative scale as the bedroom is to the living room, and the living room is to the porch.

As Grandjean (1978) describes, human eye reactions are different in different light conditions. When an individual comes from a dark room to an illuminated one, and the other way, adaptation of eye takes place. The whole process may even take more than half an hour. The weakening and tiring of eye is caused by forcing too often such an adaptation. The division into dark and illuminated zones in the habitat means a separation of two areas: the one of day illumination, and the second one of dimmed light. Some of the rooms would require almost constant illumination of high intensity, the rest would need rather dimmed, calming light. This also depends on the way the rooms are exploited. For example, at Space stations there were complaints about intensified illumination disturbing falling asleep. The cyclical, automatic dimming and illuminating of lights in the habitable parts of the base was required to divide the day-active time from the night–rest time, despite of continuity of work performance (shift system) (Stuster 1986).

Noise is especially unfriendly to such activities like talking, sleeping, resting, and psychical concentration. The zoning of different acoustic intensity should foreclose of conflicts among different activities. For an individual who is falling asleep listening to noisy conversations is as aggravating as being hushed for those who want to play.

The separation of the working area from a relaxation area would give to the habitants a sense that they 'go to work', or 'stay at home' Dubbink (2002) suggests. Multi-functional space without any partitions into smaller rooms for diversified functions would not be a good idea, as it was in case of Salut: it was received badly by the crew. The lack of separation of a working function from a living function do not allow habitants to rest comfortably and efficiently. Also, after some experiments in an underwater habitat Tekite it was suggested to avoid large multi-functional common space, which would become the scenes for conflicts (Stuster 1986).

Communication: Communication tracts in a base serve to relocating between different zones and rooms. A good communication system is the one, that assures efficient moving around the base, prevents traffic-jams creation, organizes the movement in an optimal way. Communication should allow optimal functioning of the habitat, at the same connecting and dividing it into different areas and rooms. The excess of communication in the habitat is unfavorable; however, it is safer, when there are two efficient evacuation tracts from every place in the base. As Dubbink (2001) notes, 1m^2 of habitable space at a base on Mars is more expensive than anything on Earth, and this is why there is in no room for an unoccupied space in there. The most desirable are multi-functional corridors, halls.

Ergonomic: Ergonomically planned space in Martian base is necessary to assure for the habitants some comfort of moving around. However, as Allen and others (2003) note, most of the researches on ergonomic planning of the habitable space for people were conducted in Earth's conditions. The knowledge about micro-gravitation conditions is still not completed. In the meantime, there have not been conducted any researches on psychological or physiological human abilities in the environment with lowered gravitation yet. Thus, ergonomic planned for the first Martian habitat would be intuitive only, insofar as any special simulations are conducted.

It is possible to anticipate a possible behavior in 1/3g due to analyses of differences in individual's moving around at Space stations and in 1/6g on the Moon. The value of gravitation influences the way people move from one place to another. In 0g environment people float in the air and all directions are allowed; a relaxed individual there holds in a fetus position. In 1/6g a body is slanted forward and it is difficult to walk, it is easier rather to jump softly from one place to another; however, it is easy to fall down then (what can be observed on films from Apollo mission). There are also possible 50cm high steps with putting in the same effort that on Earth is needed to step up a 17cm high stair. On Mars there could be anticipated also steps extensions and stepping up high stairs easily. A lighter walk causes rising up of a body higher; it is easier to wave an arm further.

Independently of the gravitation differences, this is environment different from the Earth's one, which a human being is not used to. There are necessary conveniences to keep the balance or to stop. The design of such elements has been precisely defined only for micro-gravitation environment in NASA MSIS STD-3000 standards. The clues in there might be partially adapted to plan a Martian base.

The need for privacy: The need for privacy is one of the basis psychological needs of a human being. Depriving people of their privacy, staying alone, has a detrimental influence on people, especially, if it continues for a long time. The negative fallouts of discounting the problem at the initial Space stations has been felt very soon. That is why Mir, the Russian Space station of a new generation (multi-modular), was equipped with private cabins. They were small but received with astronauts' gratitude. Stuster (1986) recalls that on the warships and submarines there were assured by the Navy only private bunks to have some privacy for the marines. However, even those sometimes had to be shared by two marines. At the same time the need to keep a private place is one of the fundamental needs of a human being; some space belonging to the individual only, where nobody can enter without permission. According to Stuster the size of such place should be large enough to fulfill the privacy need. There were cases noted that in the Navy and in underwater habitats private space per person was only up to $1.2m^2$! Stuster suggests a minimum assured would be no less than $2.4m^2$. There are many suggestions in different sources that for an individual it is enough to have $10m^3$ of a cubature of some private space, as Puerto Rico Group (1989) notes with dissatisfaction. Allen and others (2003) additionally note that the longer mission time the greater is the need of a larger private place.

Stuster (1986) argues that besides private cabins, there should be at least one room assured for silent reflections, psychical rest, for some individual—private—work, which could be used by every member of the crew. It might be e.g. a library.

A place to throw a party, and for other social events: The need to be together with others, social contacts, exchange of views, common talks, arises from the human being's nature. In the Space, far away from the native planet that need becomes stronger. Spending time with people, who experience the same things, and getting to know people, gives a sense of existence and importance, and what is the most important, a feeling of being a human. The mutual trust gives a sense of safety, and it bears a great influence on the psychical comfort. The interiors of Martian base should be designed to promote positive interactions in the group (Stuster 1986). As a place for events to take place could be e.g. a mess. Having meals together blends people together. Also, taking care of 'humanity' and aesthetics of a place is very important. Marines could feel themselves as people, and not only as soldiers, on submarines during meals: they could talk, and carry on not only shop-talks. That is why the mess on many submarines was inlaid with wood paneling, tables covered with tablecloths, and there was decorative china used to serve meals. There were highly appreciated some nicely decorated dining rooms. According to Stuster to keep the group together it is enough to hold one meal together per day. Eating together is appreciated only then, when nobody is distinguished at the table. It can assure some freedom to carry talks and possibility of taking different places at the table (Puerto Rico Group 1989, Perino 1991).

Celebrating holidays, anniversaries, spending non typical days distinguishably played a great part in all of the researched ICE. Also, possibility of watching films together and playing games to occupy more than one player is more appreciated there. The architecture has to meet those needs.

Personalization: The possibility of setting up in a private cabin, according to habitants' own visions is of a great importance. Every one should have opportunity to establish their own surroundings: to arrange them to feel at home. A place, that one could treat as their own, to keep their personal belongings there, to hang up family pictures, keep souvenirs etc. Puerto Rico Group (1989) underlines that a personal order in a private place gives a sense of safety, which is very important in a strange environment. The more one can arrange their own room to their needs, the greatest comfort is assured, and first of all—psychological. Private cabins should be designed to let the maximum of personalization. They should be equipped in such elements which give some possibilities to externalize their own individuality and to keep things according to their own tastes. Dubbink (2001) adds that a possibility of personalization of a working space is also appreciated, whenever it is possible to. There also could be some decorating elements created by the crew members introduced into common space. However, such decorations and rearranging of the public space should be under control. The best would be situation, when a leader is in control of such changes (Stuster 1986).

Diversification, possibilities of choice, making changes: Exploitation of similar elements and repetitive ICE schemes is received as boring and irritating (Puerto Rico Group 1989). Monotonous surroundings in different Space habitats has negative influence on the crew morale (Dubbink 2001). A visual diversification of different places in a habitat is received well. As Dubbink continues it is underlined that a different place serves a different purpose, along with the diversification effect. The increase of psychical comfort is influenced also by the diversity of elements, shapes, furniture, ways of separating places, introducing decorations and usage of different colors (Puerto Rico Group 1989). A possibility of introducing individual changes is especially highly appreciated. As Evans and others (1998) write, the surprise effect in an ICE's monotonous environment disposes the habitants positively. At polar stations, some time to make decorations for different celebrations was gladly spent. As Puerto Rico Group (1989) writes, some kind of escape from routines is crucial in isolated habitats, e.g. celebrating together different occasions in rooms decorated for the occasion. This is why there is appreciated a flexible space of undetermined function or some special multi-functional places with elements of interior design easy to move around, some mobile partitions etc. (Evans and others 1988, Dubbink 2001). Stuster (1986), and Evans and others (1988) list different ways of spending free time appreciated by habitants of isolated bases. They need diversified rooms, e.g. to read books in a silent library, to play darts in a game club-room. Due to the limited space on hand, but still, bearing in mind a human aspect, an architect should approach the problem of relaxation and entertainment zones in Martian habitat carefully. The more space, diversified in looks and purposes, the larger range of possibilities and diversification of spending time there. It is of a great influence on the quality of living, especially for long term missions, as e.g. Martian mission. As Allen and others (2003) underline, when a mission takes a long time, a highly effective rest is crucial, what could be assured with supplying with diversification of forms of entertainment and relaxation.

Contact with open space and nature: It has been many times underlined in the professional literature how important is a possibility to look out of the window in an isolated habitat. Stuster (1986) notes that this activity is absorbing and at the same time provides people with calming effect. According to him at least one large window is crucial in such a habitat. The more diversity of looking out of the habitat, the greater is the sense of comfort. The need of contact with an open space, which is easy to provide with windows, is one of the fundamental human needs. It is underlined often how important are windows among other elements of the architecture, functional and providing comfort: windows give a view at the outside equipment, a sky, surroundings of the habitat, and they lower the sense of tightness, they are the source of an interesting entertainment (during all of the Space missions it was noted that all the astronauts and cosmonauts spent much time at windows). Windows also allow the sunlight to enter the insides. The architect should make a detailed analysis of the problem of windows arrangement, or other elements that could connect visually habitants with the outside world, to make sure that the comfort of using them is on the highest level.

As it turns out, similar beneficent influence on the habitants' psyche have monitors showing the cameras' view of the outsides of base, as well as landscapes on displays, pictures, photos, slides etc. (Stuster 1986, Evans and others 1988, Dubbink 2001). However, they are not as highly appreciated as windows are.

Any contact with nature in case of Space missions is possible only by looking after plants cultivated in an artificial ecosystem, because there are no plants outside: there is no life. In every ICE any possibilities to stay near plants and looking after them were the most appreciated activities to perform in free time (NASA ALS 2004, Stuster 1986). As Puerto Rico Group (1989) underlines, human beings need contact with nature very much, because they are a part of it. Any opportunity to dwell in green, alive surroundings, and watching animals (e.g. fish in a fish tank) calms down and mitigates people, and it may be inspirational at the same time. Any possibilities of lowering the artificial effect of an isolated habitat are crucial, and looking out of the window is not enough to fulfill this need. As Puerto Rico Group (1989) continues such positive effect on an individual may connote associations with well known and remembered positively places on Earth, e.g. a green forest with the smell of trees. In their elaboration they were named 'spiritual landscapes'. They may be elicited with tools accessible for architecture.

Conclusions for architect

On the basis of elaborations above the author notes the general tips concerning the designing of a human-friendly habitat on Mars:

1. The low comfort assures survival conditions for people. The high comfort assures taking care of the participants' good condition and their psychological health. In case of a long term mission to Mars both the low and high comfort are crucial, because people can tolerate a lower standard of life conditions for a short time only.
2. There has been not elaborated precisely a minimum size of space that an individual needs to live. The rule is, however, that the longer an individual has to stay in one place, the larger the place should be. The same rule applies to the public space and to the private space, separately partitioned. Because the manned mission to Mars would be a long one, the expected private and common space should be large.
3. Due to the small cubature insofar used at Space habitats, the only provided standard was to assure low comfort. However, in an adequately large building, as a base could be, it could be possible to to take care of the appropriate high physical and psychical comfort of the habitants.
4. People are the key factor of manned missions to Mars, and it is why the whole architecture of the mission should apply to them. A human-friendly architecture is one of the crucial problems of manned missions.
5. The quality of life is directly connected with architecture. Its quality influences directly the efficiency of the crew's efficiency. This efficiency bears a direct influence on the mission success. The architecture is, as it can be seem, one of the priority questions of manned missions to Mars.

6. Architecture may play a minor or a major part in many different questions concerning the quality of living. With the help of its tools, architecture may affect among others safety, acoustic, illumination, and adaptation of a habitat to individual needs.
7. One of the cardinal psychological needs of an individual is the need of a private place, where nobody can enter without permission. The place should be large enough (in extreme conditions the minimum is $2.4m^2$). The more personal influence is possible, the more comfortable the place becomes.
8. There are needed some researches on simulations to collect necessary information about the right ergonomic to be applied to Martian habitat. Without it, ergonomics of the first Martian habitat should be based on intuition. On the basis of differences in walking on Earth, on the Moon and on orbital stations approximate psycho-motor possibilities of an individual might be defined.
9. There are preferred flexible places in ICE. The monotonous interiors are irritating, but diversified interiors, well adjusted to introduce changes, are highly appreciated.
10. The zoning in a habitat allows for conflicting functions to separate. In different parts of the habitat there should be located public and private, dark and illuminated, loud and silent, working and living zones.
11. There should be planned acoustic partitions and materials absorbing sound to improve the acoustic environment in Martian habitat.
12. Comfort, psychical as well as physical, is associated with some defined effects. It might be achieved with the specific architectonic acts. Table 4.3, elaborated further by the author, shows the list of desired effects, and different architectonic tools to provide them.

Table 4.3 The methods of introducing some specified effects that are the basis of the comfort in the Space habitat with the help of architectonic tools:

The intended effect (the comfort's basis)	**Methods to provide the intended effect**
efficient LSS	right disposition of all the parts of equipment;
comfortable movement in the habitat, reaching for different instruments and usage of equipment	ergonomic design of working and living places, and communication tracts;
division into different functions	zoning; separate places / modules intended for different functions; visual and acoustical partitions between zones for different intentions;
possible choice (food, company, the looks of the place, ways to spend free time)	kitchen equipped in a way to allow one person to cook (a chef), a group of people to do so, or individually; many rooms for different functions, enabling people to spend their time in a diversified place of diversified characteristics; flexible interiors enabling people to making individual changes (the ways of separating the space, the illumination changes, the display of furniture and instruments, introducing decorations);
optimal illumination	well planned illumination sources, their disposition and direction; analyzed disposition of windows and skylights; automatic dimming of lights at night; possibility of working with the intensity and color of light to change the interior look; specifically dimmed night light; informational lights (e.g. for evacuation tracts);
watching landscapes (far-away views)	many windows or transparent partitions, giving the view of the outside surroundings of base, planned in comfortable places; displayed landscapes as posters, photos, pictures and wallpapers well-adjusted to the room; space created to make an illusion of spaciousness;
variability of environment, surprises	flexible interiors, to make it possible to rearrange partitions creating them; modular and mobile interior elements; mobile illumination;
homely atmosphere in the habitable part, and not-distracting interior design for working places	right use of color, illumination, choice of furniture, possibilities of putting down and hanging up private belongings etc.

5 Habitats in Extreme Conditions

5.1 Habitats in Extreme Conditions on Earth

There are such areas on Earth where conditions are especially friendly settlements. There is also the largest density of settlement in those places. However, there are also such areas, where people can hardly survive in because of extreme conditions. Even those, humans learned hot to live and work there. This is possible because of specifically built habitats. They are constructed in a specific way to survive in extreme conditions an assure for habitants safety, and even some comfort level. The author here has analyzed different kinds of extreme environment on Earth and has chosen those, which due to different reasons are similar to Mars. Next, several habitats in those kinds of environment have been researched to specify suitable technological and pro-humane solutions. In the conclusions for architect there has been listed the author's observations which might be valuable for the designer of Martian base.

5.1.1 Polar Habitats

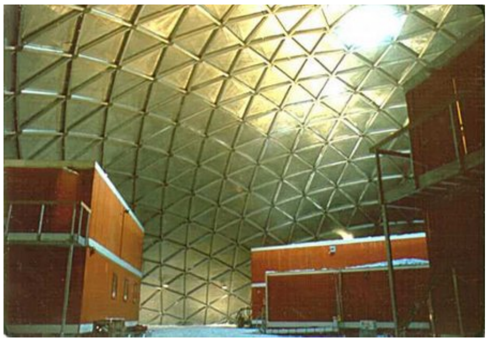
The coldest regions on Earth are Arctic and Antarctica. The majority of those terrains is under domain of the eternal winter, some parts of them are created by continental glaciers. There is exceptionally poor flora, and there are no trees. Such terrain is mostly flat and not sheltered. Because of that the winds there can reach great speeds, up to 324 km/h. Antarctica is the most windy area on Earth. Because of the poor sunlight the temperatures there are very low, the minimal temperature noted there was -89.2^{O}C). Most of the year the sky is cloudy, and only about 100 days are sunny. Paradoxically, this is a very dry terrain, because the yearly precipitation is very low. The blizzards are connected with picking up the snow reclining on the surface (*Wikipedia 2007*). So they are similar to Mars, there is very cold, dry, lack of flora, and poor sunlight.

Igloo: Polar habitats made by the natives in Arctic exploited local sources, such as ice and snow. Those materials were used for building houses—igloos. They were provisional constructions, which may melt when the temperature would rise, or just covered with cumulating snow during a blizzard, or could be just left when people moved out to another place. For more information see section 6.1.5.

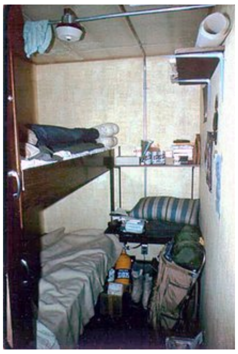
Amundsen-Scott's Polar Station: (Pict. 5.1) is located almost at the south pole, where there is dark and cold polar night for half a year. Scientists work there during the whole year. During winter season there might live 23 people. Over half a year the outside communication is limited to the radio an e-mail communication.

The polar station consists of the habitable dome and several magazine buildings in the shape of half a cylinder.

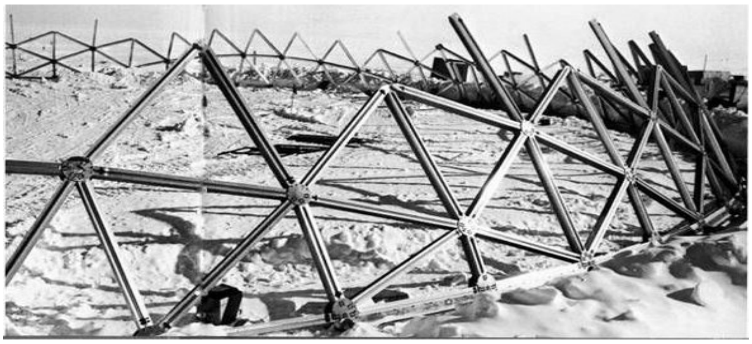
Picture 5.1: The general view on the Amundsen-Scott Base (southpolestation.com)



Picture 5.2: Interiors of the dome (southpolestation.com)



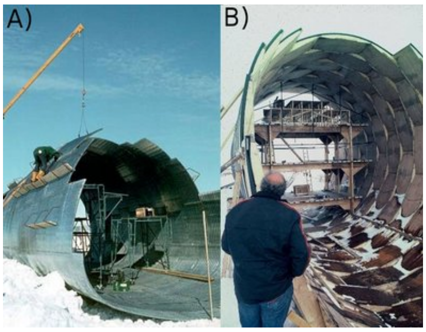
Picture 5.3: The insides of a private cabin (southpolestation.com)



Picture 5.4: The dome under construction (southpolestation.com)

The dome's diameter is 50m and the height is 16 m. This is a skeleton construction from aluminum elements built on wooden platforms properly dilated, and on plywood mats (Pict. 5.4). There were aluminum panels in the shape of equilateral triangles (they were screwed into in 6 points and later, after about 15 years, when they needed to be replaced, it turned out they were not the best solution). To prop the construction there were scaffoldings indispensable in a shape of wide trellis towers, and a team of professionals (The Pole Souls 1987b). Inside the dome, there is a habitat built. Despite the lack of windows, it is illuminated (thanks to hanged light-emitting ceiling panels) and cozy (there is no wind or snow inside). The dome was build during three summer seasons in 1970-73 (during polar days). The construction of the cover is air-tight enough to keep inside the heat for people, instruments, buildings, lamps, and it cannot seep out. The advantage of such a construction is that the snow cumulating on the dome's cover does not melt and does not become heavy, and there is no problem to remove ice.

Residential rooms and laboratories are located in three two-storey container buildings (Pict. 5.2). They were brought by planes as w whole, and that is why they are comparatively small. The residential rooms are small, enough for two habitants only (Pict. 5.3). There are some pieces of the furniture: a bunk bed and a humble stillage for personal thighs. However, the common rooms are slightly more spacious (The Pole Souls 1987a).



Picture 5.5: The structure of the station's tube: A) Halley III (metal), B) Halley IV (wood) (British Antarctic Survey)

Picture 5.6: The view of Halley IV made from metal tubes before covering them with snow (British Antarctic Survey)

Picture 5.7: The tunnel under ice (British Antarctic Survey)

Picture 5.8: Container buildings on the platform scaffolding (Halley V station) (British Antarctic Survey)

The magazine and equipment space was covered with metal arches from trapezoidal sheets, propped in a form of extended vault, finished with wood front walls, with big, comfortable gates. There is no special floor under the dome, flattened snow is used as one. The magazines are connected with each other and with the dome with half-a-cylinder sleeves.

Halley Station: The first English Halley I Station was built in 1967. There was a group of wooden cabins, that disintegrated quickly. The next habitable and laboratories buildings of Halley II were strengthen with metal roof trusses, but still, it was not enough. Halley III Station was build from trapezoidal sheets of steel tubes (Pict. 5.5A). The streamlined shape conduced the snow to slide down from the surface.

Picture 5.9: Halley VI Station (British Antarctic Survey)

Picture 5.10 The Neumayer under-ice station, there are only escape hatches visible on the surface (Alfred Weneger Institute)

Picture 5.11: The insides of polar station Neumayer (Alfred Weneger Institute)

Picture 5.12: The scaffolding for residential containers inside the under-ice tube at the Neumayer station (Alfred Weneger Institute)

Picture 5.13: The entrance gate to the under-ice Neumayer station (Alfred Weneger Institute)

At the same time, cylindrically shaped trapezoidal sheets were rigid enough not to diffract under the weight of snow. The Halley III Station was located on Ice Shelf Brunt, where the yearly snow precipitation is about 1.2m high, so the cylindrical constriction was covered quickly (Pict. 5.7). There were left visible only escape hatches, propped high enough. Halley III Station was used for 12 years, until it became to dangerous to go down inside safely. The construction started to diffract under the snow weight. Halley IV Station (Pict. 5.6) was similar in structure to the previous one. However, the tubes were made that time from wood panels (Pict.

5.5B) with special apertures to avoid quick escape of the heat from the habitat to the ice above and on it. Wood panels are not as rigid as metal ones, and while they were still under construction, cumulating snow caused diffraction of the building and considerable loss of durability under the weight of snow. The station was inhabited for 2 years only. Halley V consists of habitable containers propped up on the steel scaffolding (Pict. 5.8). The construction elevates the habitat high above the snow level so as not to allow it to be covered with snow too fast. Today the newest station, Halley VI, is still under construction. Its designers took care about connecting its usefulness as well as its attractive looks (Pict. 5.9). Modern metal modules are propped up on retractable legs to separate the station from cumulating snow underneath. The legs are equipped with skis to move the whole station to the chosen place. Modern buildings assures human-friendly insides as well (BAS 2006).

Picture 5.14: A view on the net of tunnels Thule town before covering with snow (Bob Brewer)

Picture 5.15: Entrances to the under-ice town - Thule (Szolginia 1987)

Neumayer Station: German polar station Neumayer located under the ice consists of two metal tubes, each one 8m in diameter and about 90m long (Pict. 5.11). There are special scaffoldings inside (Pict. 5.12) creating a flat floor to hold cuboid containers for working and living. The equipment is also kept in them, as well as the vehicles. People can go inside through the escape hatches (Pict. 5.10), and the vehicles go inside over the batten (Pict.5.13) (AWI 200).

Thule Town: Near the Inuit town Thule, there was a large airport built in 1951, in vicinity of which different buildings were constructed from steel and aluminum soon: planes hangars, workshops, magazines, habitats for the airport crew, a power station, water plants recycling salt sea water into drinking water, and many residential buildings. A town for several thousand residents came into existence. The rough climate made Americans to elevate their houses above the snow level. It was done also to fulfill safety standards: the base could be camouflaged better that way. The first tunnels were built in 1955. They were 3.5m deep ditches, covered with vaulting made of ice-blocks. There were a dozen or so such ditches made, each one 24m long. In time, the construction methods were improving, and the tunnels were drilled in the ice sheet alone. One of the tunnels is made 350m deep under the ice, divided into 3 large chambers 60-90m long, 6.5m wide and above 2m high. Next, there were introduced metal tube constructions. Initially, they were put on the surface (Pict. 5.14), and in time covered with snow layers. There were small escape hatches left on the surface only (Pict. 5.15). Under the ice, a town of Thule was established with those connected tubes. This unique town is just a large system of tunnels, drilled in ice, as well as the metal tubes, all of them connected together. Some of them are communication tracts, where electric trains work for transportation, several other function as store rooms for different instruments for the airport, some others serve as residential rooms, sports rooms, entertainment rooms etc. The habitants of Thule do not go outside for weeks, so they need to have everything they need to live a normal life at hand (Szolginia 1987, s.150).

Conclusions for architect

On the basis of analyses of polar habitats conducted by the author, four types of constructions were distinguished that could perform well in extreme conditions similar to Martian ones: igloo, under the ice tunnels, container buildings on scaffoldings, and metal modules on legs. It is possible to adapt those solutions for the specific Martian needs. The problems concerning their exploitation faced in Arctic and Antarctica should be put to attention of an architect in some points.

1. Ice constructions (igloo) and those built in the ice (tunnels) were in use on Earth in extreme conditions before, and performed their duties well as habitats and working places. That is why analogical structures could be exploited on Mars as some of the elements at the base. The limitation point might be a temperature growth above $0^{o}C$ that would melt the ice or over-charge the construction with the rock-mantle coming with the wind. Thus, ice constructions may be built successfully at the latitudes where the temperatures stay below zero all the time, or the ice should be protected against sublimation. It should be evaluated under what weight a tunnel made under ice would hold in 1/3g conditions, and what Martian dust layering may be anticipated on the chosen area for building a base.
2. The most problematic at polar latitudes on Earth is snow cumulation on buildings, where the snow covers everything in time. Common wooden cabins well insulated could provide people with good life conditions in Antarctica and Arctic. They were left only because digging the tunnel entrances in snow became too tiring, sometimes even impossible. That is why this is so important to anticipate how deep Martian dust cover is possible on locations chosen for the bases. Cumulating of rock-mantle may cause the habitat to become entombed. There have been different solutions put into life for many years to eliminate the problem at polar stations, so Martian architects may learn from others' experience. Digging out is work and time consuming, as well as dangerous in extreme conditions. That is why two solutions to this problem were worked out. The first one seems to be suitable for places where

the cumulation of blown-on material would be moderate, i.e. under-ice tunnels. The escape hatches and gates for the vehicles should be protected from dust cumulation only. The escape hatches should be planned in advance high above the ground level, with stairs leading outside to the surface. Alternatively, as the author here suggests, they could be equipped with a retractable mechanism to lift them up when necessary. The second solution, for the problem elaborated here, is to build the scaffolding with a platform to arrange residential containers, or to equip those containers with high legs. The scaffolding is more complicated to build, then metal stilts functioning as legs. However, there might be different modules put on it, some added or changed easily. There might be only specified, architecturally designed, adapted modules put on the stilts. Those legs, however, posses some different advantages. It is easier to assembly them and to stabilize them on the surface on a chosen place. It is also easier to retract them and change their height, and to equip them with elements to move them on surface. In case of Halley station, the legs are equipped with skis to move them on the snow. However, the surface of Mars is very uneven, covered with rocks of different size, so the smooth moving of the whole habitat would rather not be possible. The idea of moving the habitat is, however, very inspirational. Thanks to the change of the location of Martian habitat there would be picked some more promising places as about weather conditions, access to the sources, a kind of an attraction of place etc. There could be legs designed for a Martian habitat equipped with wheels or articulated legs moving like insect's legs. Walking legs are one of the ideas considered by NASA.

3. There were considered for polar habitats two means to minimize low temperatures' influence from the outside layer of base on the insides. First, it was a sheltering from cold winds blowing e.g. in the shape of a dome covering it, or putting the whole base under a surface, far from the negative atmospheric influence, e.g. in ice tunnels. Setting the habitat under surface assures better temperature stability, i.e. smaller temperature's fluctuations. The protection against the point of contact with the cold foundation may be provided with scaffoldings under main constructions. On Mars, the thin atmosphere would slower receiving the heat escaping from the habitat than the cold ground, which could also keep the heat inside. Distancing the whole construction from frozen foundations assures better even temperature dispersion around the building. However, the scaffolding would rise the costs of building.

4. Extreme temperature conditions and snow storms made building process of polar stations difficult. There were two solutions elaborated for the problem. First, the building season was chosen for the summer time, when weather conditions are favorable, the sun shines and when it is not so cold. Due to the fact that favorable conditions occurrences were rather seldom, the more complicated works were performed for a long time and they were divided into several summer seasons (in case of the dome of the Amundsen–Scott station it took three years). The second solution was to make the job on location as

easy as possible. The cubature of residential constructions was adjusted to be easy to be carried by transporting planes. That is why the small, cuboid containers were established, unfortunately tight and uncomfortable. However, they were prefabricated as a whole in a comfortable place, in factories. They could have been tested as well there, and made sure that every detail was made correctly before they were sent to the pole. It was as easy as that: a finished module was propped on the scaffolding platform *in situ*, and that was it. However, the transportation costs were high, what would be especially negative in regards of Martian base.

5. Polar buildings were to function as a shelter for people against the life-threatening environment to assure their survival and and a safe room to work. The humanitarian aspect of the shelter was not taken into consideration too much. It has been described in section 4.2 that it was one of the reasons of socio-psychological problems. The dome of the Amundsen-Scott Station is an attempt to assure slightly more comfortable living conditions for people, and even some room for entertainment. It is not heated and there are no windows, but there are human-friendly conditions, and people who need some room for physical activity, especially during the long polar nights, might perform it safely. There could be similar solutions applied to Martian base. Some optimal living conditions would be assured only in the habitat and the working places. LSS exploitation is very expensive, so in the recreation place it could be used only when needed, or even not used at all (Kozicka 2004a). The said places could be sheltered with a construction protecting it from winds and dust, there could be a floor, lights, but people could use there their oxygen masks, or warm clothes, in the same way as under the dome of Amundsen-Scott station. There could be a cultivation area, sports gym or a room with a view. This zone could be for a provisional use and for volunteers only. That way it could be built without the barrier protection against Cosmic Rays. Martian atmosphere blocks it partially, so a short-time exposition to it should not be dangerous for the habitants' health. A swimming-pool could be planned in the same way. It would perform as a barrier against the Sun and Cosmic Rays for the inside of the habitat, and at the same time it would allow people to swim and perform some free-diving. Some contact with water would keep people in a good physical and psychical condition. Solutions to this type of zone may be diversified.

Picture 5.16: A modern Belgium polar station Princess Elisabeth, a project (International Polar Foundation)

6. There has been more attention put to the aesthetics of a polar station for same years now. The buildings look more colorful and are shaped in a more interesting way (Pict. 5.9, 5.16). There have been taken into consideration not only safety problems of a shelter, but a human-friendly aspect as well; the problem of a human aspect can influence significantly on individual's psychical comfort. People feel better when they are taken care for and when their houses just look nice. It is worth to mention that the cost of building an aesthetically looking building could not be really higher. The fact should be kept in mind while designing Martian habitat.
7. Vibrant colors, characteristic exterior shell and inscriptions could help to recognize the polar habitat in the white background by the teams coming back from an expedition, and for in-coming planes. This seems as a useful clue, as well as the idea of making the place with much more aesthetic applied to it. There is the dominance of pinkish-reddish landscape on Mars, so the colors for habitat should be selected to make it easy to find it in the landscape.
8. Looking at the architecture of polar stations there might be noticed two solutions of locating different functions, what might be helpful while planning Martian habitat, depending on chosen building technologies. The first one is to locate different functions in separate buildings which are simply constructed in different ways, the second one is to locate the functions in buildings constructed the same way. Each solution has its advantages and disadvantages. Locating different functions in separate buildings enables to adapt them better (Kozicka 2007). The habitat of Amundsen-Scott station is located under the dome, habitable containers are heated and insulated, and garages and magazines are located under the vault made of metal sheets, where there is no need to heat it, so it was easier to make large entrance gates in the straight front walls. Less demanding functions need easier, cheaper constructions, and more demanding functions need more complicated and well adjusted constructions. That way the costs are allocated for the most demanding functions, what cuts the costs for less demanding functions. There are used the same constructions in the second solution, where any type of a function might be located in any of the buildings. Modules assure higher safety level with the use of habitable elements of the base and more flexibility of the space at hand. However, not every construction could be economically exploited that way. The tunnels of Thule and of the Halley III and IV, and Neumayer's base seem to be good candidates worth imitating on Mars. The form of a tube is ovoid, so the inside pressure dispersion is better. They are also easy to construct, and their assembly should be easy to perform, without additional problems. Modularity makes it easier for damaged elements to be replaced with new ones. In case of tunnels drilled in ice to make extensions, it is enough to drill some more ice, or to make more tunnels, as there is no need for building materials there. Of course, to make an ice tunnel on Mars there should be large ice sheets to exploit them. There should be found some, or some created artificially. As about the tube tunnels, is seems reasonable to

make them metal, not from wood. Special light wood panels with apertures in are easier to insulate, but there are no snow storms on Mars, so wood would not absorb water and so it would not contort. However, wood panels are thicker so they would take more cargo space than metal elements. What is more, there would be no extra wood to replace damaged elements, and it seems unlikely that there would be some soon. At the same time metal is easy to produce. An architect would also suggest some other building materials.

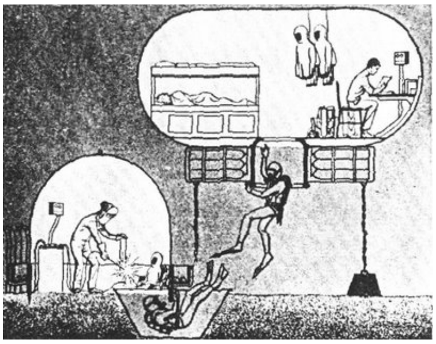
9. Assembling elements of the construction of base should be easy, to make sure that it would not be a problem to replace any of them, as it was in case of Amundsen-Scott station. Difficult and dangerous assembling may require a team of professionals (Kozicka 2004a). In case of Martian habitat this should be eliminated, because it would make Martian mission too complicated.

5.1.2 Underwater Habitats

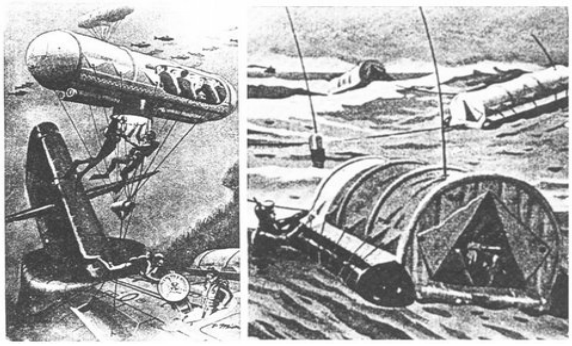
Water is completely different environment than air. It is a comparatively thick liquid, where people can not move as efficient as on the land. There are cases of a sudden weather changes in seas and oceans, which can cause a drastic change of conditions in just a few minutes. There is also less light under water as not much sunlight can reach deep into water. There is some oxygen in water, but it is not suitable for people to breath because it is diluted in water. However, there has been artificial gill invented, built form water-proof membrane, which lets oxygen one way and carbon dioxide back (AD 1967a). The larger depth, the lower temperature is and the higher pressure is. Still, for the sake of human health and comfort of breathing process it is best to breathe an artificial mixture of gas in the pressure similar to the one that is characteristic for the environment under water. The larger depth, the more light gas is needed (e.g. helium). It causes voice to become high and funny, what is irksome, and what seems to be more important it may cause misunderstandings during conversations. An individual can breathe such artificial air, but when they want to come back to the surface, they must go up slowly. The larger the depth from where they start and the longer is the time they spend in there, the more time decompression takes, in some cases even several days (Gussmann 1984).

On Mars, as under water, it is impossible to move and breathe freely. It is cold in both the places. It is also better when the pressure in the air to breathe is similar to the one around, even if it causes some discomfort.

Spid is an abbreviated name of a inflatable habitat: Submersible portable inflatable dwelling, designed by Edwin Link. Spid was a horizontally mounted oblong cylinder with ovoid endings.



Picture 5.17: Inflatable under-water garage next to the inflatable habitat, by E. Link (Gussmann 1984)



Picture 5.18: A lifeboat for submarines, a project by E. Link: A) marines in the lifeboat under water, B) on the surface (Gussmann 1984)

It was tethered to the steel frame which was anchored to the seabed with a ballast. There was one tight room inside 2.5m per 1.3m. It was spiky inside because of different instruments, so it was almost impossible to move around. People could swim into the Spid by a hatch in the floor. There was only enough room for two people to sleep and to put two chairs and a table. Spid was a house for scuba-divers. They worked under the inflatable dome tethered by the rim to the seabed to assure safe environment for work without diving suits (Pict. 5.17). They could enter the module through an underground passage (Gussmann 1984, p.62), (Link 1964).

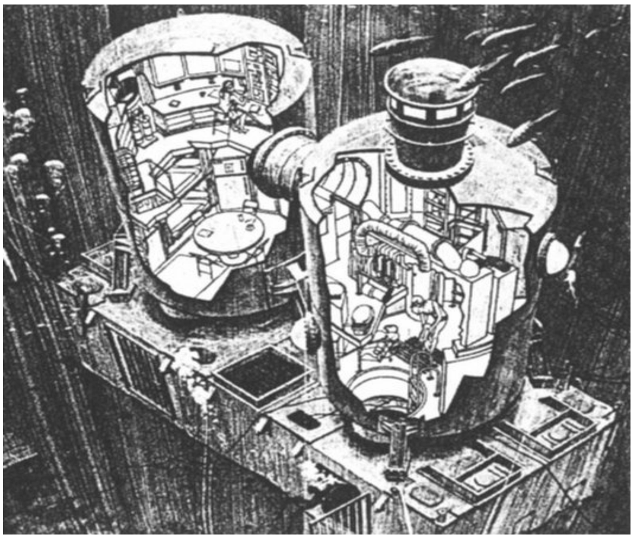
Inflatable Lifeboat was also designed by Link. After letting air in its shape was cylindrical. An inflatable skeleton assured keeping the rigid construction even when the insides of the cylinder were no longer airtight, when the lifeboat could reach the surface of water and people could get out of it (Pict. 5.18).

Tektite is the name of an under-water habitat made by NASA to conduct researches on human behavior in completely isolated conditions. To build that habitat there were used prefabricated elements of an existing Space flight simulator. Tektite consisted of two cylinders 5.5m high and 3m in diameter. It was prepared for five persons to live in. The habitat was located on a cuboid foundation, 16m under water surface (Pict. 5.19). Its artificial atmosphere consisted of 92% of nitrogen and 8% of oxygen. Cylinders near their tops were connected by a passage, 1.5m in diameter. There were two entrances leading to the Tektite habitat, both sheltered in cages as protection against sharks. It was possible to get through the open lock under the cylinder on the right to reach a wet room. There was a ladder leading to the control room, which served also as a food storage room, two-months amount. There was a control turret atop. There was a laboratory in the second cylinder at the second floor, and below, there was a habitable place, with a mess and an entertainment corner (Gussmann 1984, s.68).

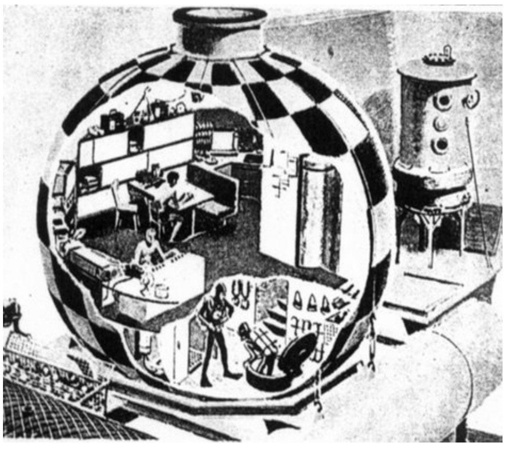
Precontinent is a name of under-water habitats that had been designed and later inhabited by the famous Jacques Cousteau's team. Precontinent II was the first in history under-water subdivision. There were three buildings: The Starfish, The Rocket and The Onion.

Their outer layer was made from riveted sheet metal. The Starfish was anchored 10m under water. It was a considerably comfortable habitat. It consisted of a central part, spheric-like, and four outstretching cylindrical arms. There was the main part in the center, the common room, also serving as the mess, and the control center. Two of the arms were for private cabins, and one of them contained laboratories and a toilet. The last one was the wet room, with an open entrance to water, and the dressing-room for scuba-divers. There was enough room for five people in the Starfish to stay. The temperature inside was 21^{O}C, and humidity 85%. The Rocket was anchored a little bit deeper, 26m under water. It was a vertical cylinder divided inside into 3 levels. There was a modest private cabin at the top, in the middle there was a wet room leading out, and at the lowest level there was a room with a cage for protection against sharks. From there, people could go down to reach 110m under water in a special diving ship. The Onion was a small module in a shape of a dome outstretched atop a little (that is why it was similar to an onion and so named that way). It was set on the seabed on four retractable legs. It functioned as a magazine and a garage for a small diving scooter, Denise. Thanks to this solution the under-water job to do could be done more efficiently than in case people would have to dive each time from the surface (Gussmann 1984, p.58).

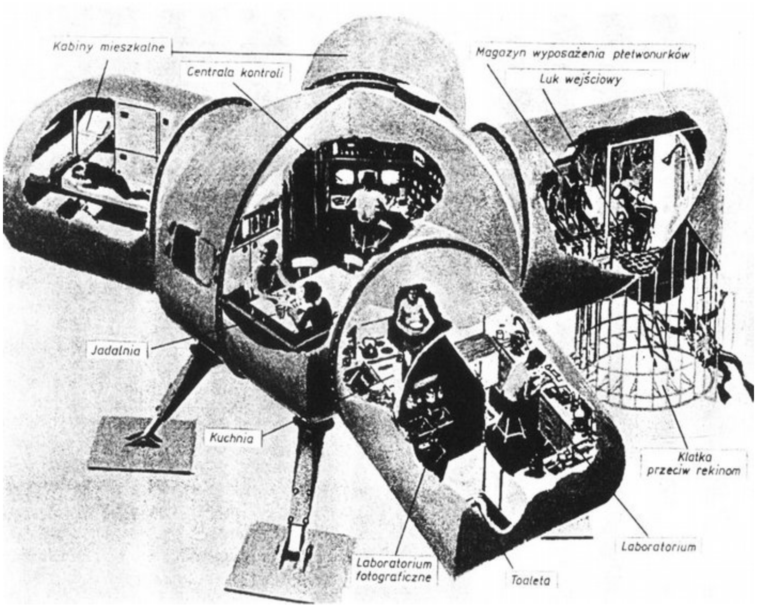
Later there was built the second under-water habitat of Cousteau's team. It was called Precontinent III. It was a sphere 5.7m in diameter. That shape allowed an ideal gas pressure inside the streamlined building. Precontinent III was divided into two floors. There were six persons, living and working. When compared to other under-water habitats, that one was really comfortable and spacious. Some of the stored goods were kept outside, on the module, where cold water could keep them in good conditions (Gussmann 1984, p.65).



Picture 5.19: Under-water habitat Tektite, a view with the insides(Gussmann 1984)



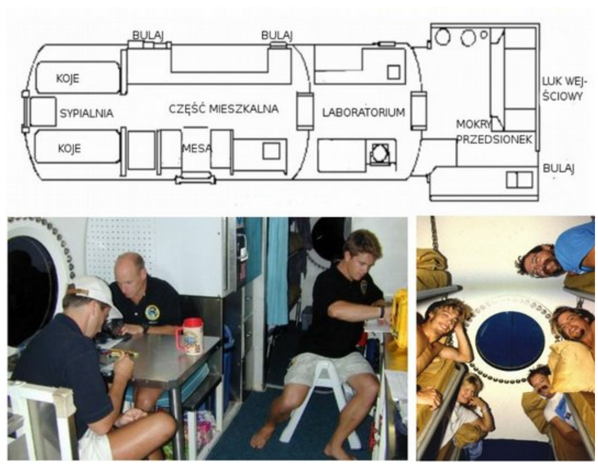
Picture 5.20: Precontinent III Habitat (Gussmann 1984)



Picture 5.21: The Starfish Habitat in an under-water town Precontinent II (Gussmann 1984)

Picture 5.22: The Rocket Habitat in an under-water town Precontinent II (Gussmann 1984)

Picture 5.23: Aquarius: the outside view (NOAA/UNCW)

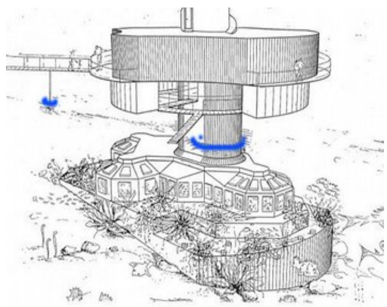


Picture 5.24: Insides of the habitat Aquarius: the floor plan, and pictures of the team (the mess and a bedroom) (NOAA/UNCW)

Aquarius is contemporary the only one under-water laboratory to conduct researches of the sea. There are three elements of it: a habitat, a buoy with the LSS system, and a platform holding the habitat on the given, specified depth. The habitat, offering 11m^2 of the living area, consists of a residential room and a laboratory. The under-water module is 82 tons heavy, 14m long, and 3m in diameter (Pict. 5.23). It was build from welded together thick steel sheets, shaped ovoid with the help of explosives. The module consists of two hermetic parts: the entrance and the main part. Ahead of the main residential-working part, there is a wet foyer. Next, there is a technical room with the life supporting system; there is also a toilet. Through this part, a passage leads to the main deck. There is a mess and panels to conduct researches, and also computers and scientific instruments. There are two portholes: one at the front and one at the end of the module. There are six bunks for the whole crew at the end of the inside corridor (Pict. 5.24). The habitat is set 14m deep under water, tethered to the bottom platform 5m below it: it assures the stability of construction. Thanks to it, there is no need for the time consuming decompression after diving, and work there is more productive. Researches that would take 60 days, take there 10 days only. After the end of mission, the pressure lowers inside for 17 hours down to 1 atmosphere, and finally, the aquanauts can swim out of it in their diving suits to the surface. The construction performs well during pressure changes. The habitat was built in 1986 and has been exploited since then (NEEMO 2006).

An under-water glass capsule is a construction made from large sheets of thick glass connected together into one hermetic module, anchored under the water. Such a thick glass is very resistant and it is easy to shape it ovoid. Glass domes are used as rest stops for scuba-divers, where they can stay for a while without their breathing masks. Picture 5.25 shows such a capsule. There are performed weddings on demand for people who are fascinated with the sea. Glass tunnels and barriers of the large cubature are well known from many oceanariums in the world. Large glass sheets are also used in modern under-water hotels (Pict. 5.26).

Picture 5.25: A glass capsule, functioning as a rest place for scuba-divers or as a wedding chapel (uwpress.com) .

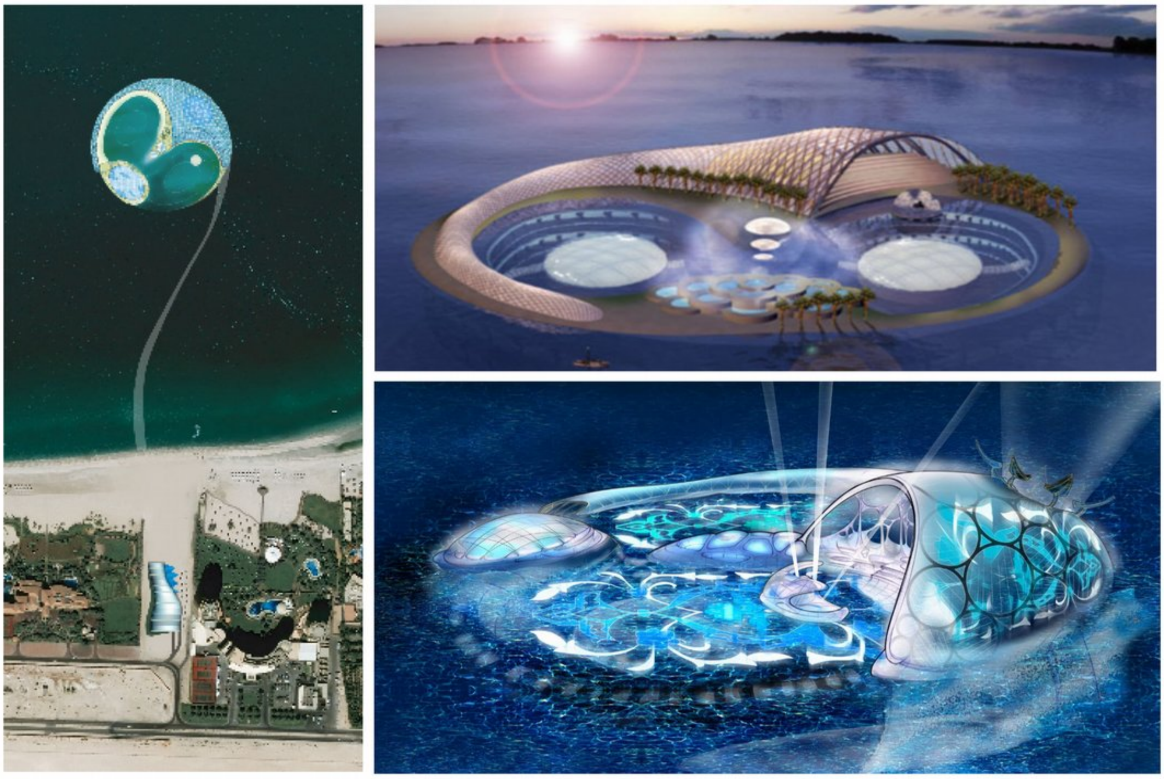


Picture 5.26: The under-water restaurant Red Sea Star (redseastar.com)

Hydropolis is a large complex consisting of two parts: an on-land entrance and an under-water part with the main attractions. They are connected with a tunnel with two tracts: for the passengers, and for the cargo (Pict. 5.27). Hydropolis is under construction nowadays, and it is planned to be finished in 2007. There would be a hotel with the ballroom, health resort, different restaurants, shops, galleries, museums, a science institute. The under-water part of Hydropolis is going to be built as a stone skeleton construction, and there would be stretched a thin, transparent membrane on this construction. The pressure inside would hold the form of the habitat and keep the construction still. The architect of Hydropolis is Joachim Hauser. The visualization of its project is shown in the Picture 5.27 (Hydropolis 2007).

Conclusions for architect

There are many similarities between conditions deep under water in seas on Earth, and on Mars. In both cases construction of the habitat is exposed to an arduous test and requires the specific kind of a project. Water, which is 70% of the Earth's globe, is uninhabited. That is why, every one who settles there an under-water house, would be isolated from the rest of the world. There have been a few houses only built there, all of them small. Most of them were inhabited for a short time only. However, the analyses of their architecture may help the architect who would design a Martian base. The modern way of shaping residential places under water, considering new technological solutions and the artistic inspirations may influence the vision of Martian architecture.



Picture 5.27: Hydropolis: situation, on and above water perspective, under water perspective (Hydropolis Proposed Concept)

1. All under-water habitats in the 20th century were small in size. That is why most of them were tight and uncomfortable. Any movement inside was difficult, especially, when there were people living there, and the LSS and all the needed instruments were working without any covers on them. There was a very uncomfortable residential space created that way. Such inconveniences should be avoided in a Martian base's plan.

2. Some of the under-water habitats was oblong and consisting of one floor only, some—of several storeys and more tapering. There were no differences in the receiving those habitats. So, the number of the floors should bear no influence on the quality of the space of Martian base.

3. The said habitats were divided differently inside. The author thinks that the most functional arrangement was characteristic in the case of Precontinent II. That habitat consisted of several parts subordinated to the central part. That arrangement creates some good influence on the residents' unity. Central module was the biggest one, containing the main common room and the control center. The most important events took place right there. The habitat was too small for every aquanaut to have their own private cabins. However, there were two separate bedrooms. In case of a conflict inside a group, parties in conflict could stay in separated rooms. A larger extension of the form would assure a window in every room, in different places. Such a scheme seems reasonable to be taken into consideration: connections of functional zones in Martian habitat could be planned in a similar way.

4. There had to be exploited specifically shaped streamlined constructions, and really resistant materials due to the large differences between the inside and the outside pressure. That is why they were streamlined in form, and made from thick sheets of metal or specific kinds of membrane. As well as metal constructions, the inflatable ones performed well in extreme conditions, similar to those on Mars in many points, so they could be adapted for the Red Planet (Kozicka 2004). They are resistant and worth recommending. In the past, there were considerably more metal under-water constructions than inflatable ones. That was the case because of a better know-how of creating a large metal surface into the shape of hermetic rings. The inflatable constructions were not so common because they were new at the time, and the technological improvements were made in time. There were not in use transparent membranes to make windows in under-water habitats. Steel creates a better protection against water predators. There are not such dangers on Mars, so the membranes become as well promising as metal hulks seem to be. Cylindrical under-water habitats were made from large sheets of metal bent with the help of a special method. Such metal rings are incredibly hermetic. That way the hulks of limited size could only be made, usually several meters in diameter. To make a bigger construction for Martian base the same technology could not be applied. To design a larger base on Mars there should be applied a different technology to make walls. Then, metal constructions would not dominate over the inflatable ones. The initial under-water habitats were built from riveted sheet metal, and the building process

was mundane. The shell would be more hermetical, if metal was welded rather than riveted, and it would be easier to do. On Mars, there should be a professional help needed, or a robot, to do the job, because it would be too dangerous for a non-professional.

5. Transparent barriers in under-water habitats are especially important to assure the possibility of a safe contact with the overwhelming and strange outside world, and at the same time having some good influence on the residents' well-being. A glass under-water module is received gladly by the tourists visiting it. Some couples wish to be married there, in the under-water surroundings (Pict. 5.25). They also did not forget about windows in the newest under-water habitat, Aquarius. There were the most important places for windows taken into consideration: the mess and the bedroom (Pict. 5.24). Windows were made in a form of a small porthole or, slightly larger, capsules. Today it is possible to make them from light, thin, elastic and transparent membranes (Hydropolis 2007). Using those materials on Mars instead of glass would be an economically accepted solution.

6. There were observed algae and urchins growing on the external shell of metal construction of under-water habitats. In such cases smooth glass was not covered with them so much, and it was easier to clean it. Considering Martian base, it is better to use metal shell, which is more resistant to dirt and dust cumulating. Mainly to the fact that it is difficult to clean the external shell in extreme conditions, and also the fact that a clean building would dilapidate slower. It has also some influenced on the residents' psychical comfort.

7. It is colder deeper under water. On Earth, at different latitudes temperature of water is different. That is why there were not always insulation materials used for those under-water habitats. Glass habitats are built also without any insulation. On Mars, possibly, insulation would not be needed for every part of the habitat. However, in places requiring insulation, like e.g. transparent partitions, it would be recommended to use not glass, but some other transparent materials, which at the same time would be an insulation material.

8. Lifeboats by Link are equipped with two trusses, which are useful in two different cases: an inflatable external shell holding up the building under water, and an inflatable skeleton, holding the construction in its shape on the surface of water (Pict. 5.18). It assures much more flexibility for the exploitation of the object. On Mars, such kind of a construction of habitable modules would be desired. Firstly, the structure would not lose its shape after being pierced, and secondly, it would be exploited as a separate structure of the base, or a kind of a house inside the larger, isolated construction.

9. Under-water habitats are adapted for people to go out of them safely. They are equipped with an airlock. Usually, it is located in a so-called wet room, along with a dressing-room. Such a comfortable and functional room to prepare oneself to go out of the base should be in Martian base. The atmospheric pressure in an under-water habitat is kept to enable an airlock to be left open

all the time, and people should not have any problems with their adaptation to new pressure conditions after and before going in or out. The pressure should be maintained in the same way in Martian base. Its value would influence the range of building material, which may be used for building the external shell of habitat.

10. Some stored goods were kept outside the under-water habitat, where the low temperature of water conserved them well enough. It was a cheaper solution than keeping many fridges inside the living-working modules. On Mars, where the temperature is low too, this way of conservation food could also be exploited.

11. As the Hydropolis example shows, being now under construction, modern technological solutions make it possible to design and build an interesting, open for human needs habitat in extreme conditions. Water environment is even more strange to humans than Martian surface. Thus, if it was possible to construct such sophisticated and at the same time a safe under-water habitat, it seems possible to find goog solutions for a Martian base. There is still an open question for solutions for the possibility of importing those technologies to Mars.

5.1.3 Subterranean Habitats

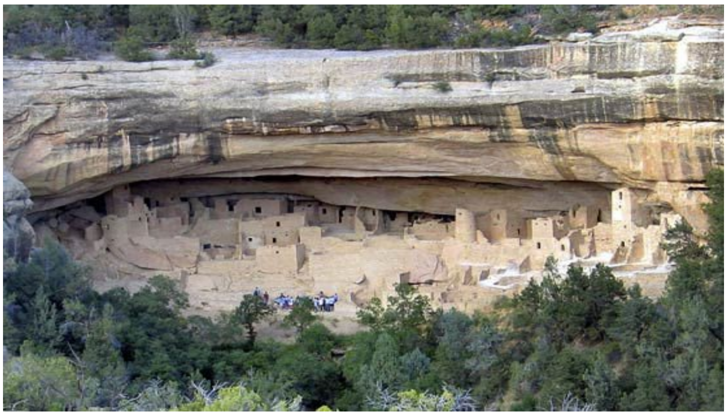
People usually build their houses on the land, where there is sunlight assured. They choose subterranean houses only in exceptional situations. Subterranean habitats assure an exceptionally effective shelter against: fickle weather conditions, wild animals, enemies. That is why they were used by the primal peoples, oppressed by enemies invasions, and for hiding fugitives. Subterranean habitats give shade and assure the stability of temperatures. Even not so deep into the ground, the temperature stays constant, almost without any fluctuations, the same the whole year round (Krarti 1998, Unver and Agan 2003, Al-Mumin 2001). Climate conditions bear almost no influence on the subterranean habitat. In the deserts of Sahara and Asia Minor the days are very hot and the nights are very cold. The local people discovered that by locating their houses under the ground they can assure in an easy way very good temperature conditions in their houses. What is more, modern and ecological, saving energy consumption houses are built under the ground, to lower the costs of heating. Subterranean houses give good protection against winds, rains, hails, snow, lightnings, and it is very difficult to damage them. However, generally speaking, they are not received very well. People do not feel comfortable without sunlight, surrounded by walls without any windows. They can feel threatened in closed rooms, and a possible lack of an evacuation way. That might be a reason of psychical problems (Temeemi and Harris 2004). To sum up, subterranean habitats offer very suitable residential conditions. It might be even said that rocks and soil protect against extreme conditions, and they do not create them. The only disadvantage of this solution is a limited contact with the surface, with the Sun and the landscape. It is of a great consequence for the sense of comfort. However, in comparison to polar and under-water habitats, the subterranean ones do not seem much worse. The idea of living in the ground arose a long time ago, among primal people. First, the existing caves were used. Next, people learned to change them, and make extensions inside (Rewerski 1995). At last, on some terrains people could recognize the kind of rock which is easy to remodel. People could hew in the rock with the help of primitive tools only, without any help of professionals, and build cheap and economically exploitative houses. Nowadays, many different building technologies allow designing a very sophisticated subterranean architecture, which stays closer to the modern expectations as to a house.

Caves are natural tunnels shaped by the nature. There are the most popular karst caves, shaped in the kind of rock that is susceptible to water penetration under the ground. The Lascaux net of tunnels is an example of subterranean habitats in the human history (over 10 thousand years B.C.) (Rowerski 1995). Those tunnels were inhabited as they were, without introducing any crucial changes in construction, apart from the decorations—paintings on the rocks. The permanence of those natural rock's forms is very high. Some of the caves date back to several thousand years ago. They can stay in a good condition much longer than common buildings on the surface built many years ago.

There are some proved researches for people living in lava tunnels in the historic times. Frederick (1999) writes such a tunnel, named Surshelliv, on Iceland, was occupied by the fugitives. There are no tracks of any construction work. A natural cave was inhabited for some time. Surshelliv is even 11m high, and about 15 – 16,5m wide. The tunnel is spacious. At one of its end there are layers of frozen water, where people could take clean drinking and economic water.

Oregon LS Society team organized a Moon base simulation in one of the lava tunnels in Oregon, the USA. The whole affair was quite amateur, but it ended with the complete success. The establishing of a subterranean habitat was successful. The participants of the simulation built small, light construction inflatable houses, inside the cave (Frederick 1999). The exploitation of the space was restrained, and the choice of construction was dictated by the outer-space mission requirements.

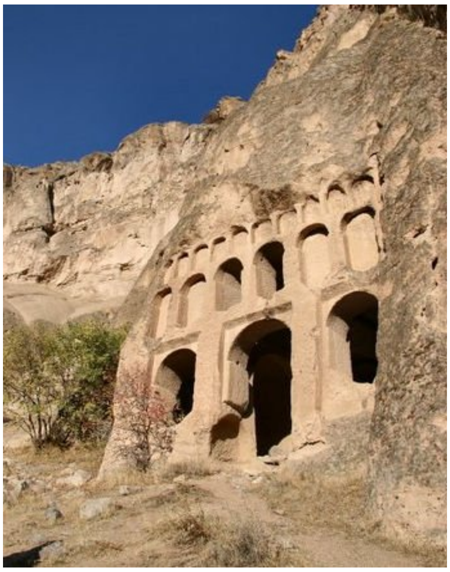
Picture 5.28: Interiors of the house of C. Cabrera (Ratajczyk 2004)



Picture 5.29: Cliff Palace (National Park Mesa Verde 2007)

The Residence of C. Cabrera: An interesting example of a modern subterranean habitat is the house that belongs to an artist and architect Cesar Manrique Cabrera, in Taro de Tahiche, on a Spanish island, Lanzarote. There are five volcano caves managed into the household, which were created by air bubbles in the congealing lava. There are some natural skylights of hornitos type. Every cave was divided into two appropriable floors. Every room was designed in a comfortable and modern way. The caves were connected with narrow passages. Most of the surface of a natural rock were left in their natural state, what gives the interiors a unique climate. Only lower parts of the walls were coated with parget and painted in white, not to let the clothes of habitants to get dirty. The interior design is shown in the Picture 5.28 (Ratajczyk 2004).

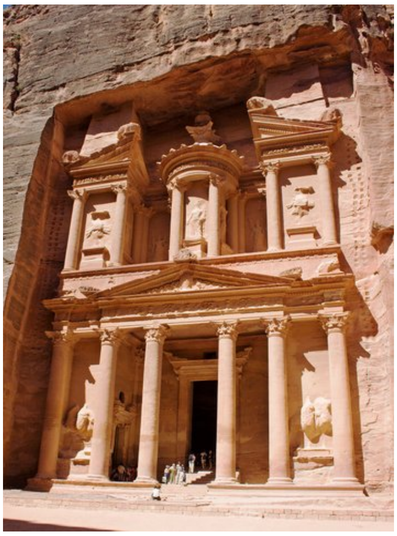
Pueblos in Mesa Verde are created by the rock niches and buildings. There are Anasazi households, Native American tribes, which had lived in Mesa Verde, the USA (*Wikipedia 2007*). The cavities in vertical sandstone cliffs were created by the nature. Only the floors were partially changed and smoothed. The niches were deep and wide enough to build spacious villages in there, consisting of many households, magazines, and religious objects. The buildings were erected from the local sandstone, easy to shape and at the same time strong enough. The buildings are still in a good condition, even though they are more then 800 years old. The greatest village there is the Cliff Palace (Pict. 5.29), which contains 150 rooms and 75 plazas. It is estimated that there could have lived more than 100 people in the Palace. The village was set in the deep niche at an almost inaccessible slope, what created a great natural shelter against enemies and wild animals. The habitants got inside on ladders or branches of high trees in vicinity. A cave would assure a shade during the hottest hours of a day, and a shelter against rain or wind. Despite of the lack of the shielding walls, there were constant temperature conditions whole year round (National Park Mesa Verde 2007).



Picture 5.30: A great rock with subterranean habitats in Cappadocia (sakwiarz.pl)

Picture 5.31: A church excavated in the rock , Cappadocia (Wikipedia 2007)

Picture 5.32: The insides of subterranean cities in Cappadocia: Kaymakli and Derinkuyu (sakwiarz.pl)



Picture 5.33: A chapel carved in limestone, Petra, Jordan (Wikipedia 2007)

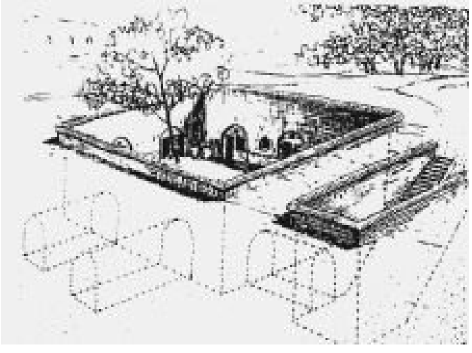
Picture 5.34: The view of Guadix, Spain (Wikipedia 2007)

Subterranean households in Cappadocia (Turkey) were built even 6 000 years ago. They were excavated in the tuff rock. As the tuff is considerably easy to process, some primitive tools and technologies were enough to mould it. Tuff, at the same time, is also durable, and that is why even today there are to find many of such households in their initial form. Common households are irregular and ovoid in shape, and every one is exceptional and singular, despite of its simplicity (Pict. 5.30). Households of Cappadocia consist of several chambers located on different floors or on one floor. Their picturesque aesthetics has been enrapturing since they were discovered. There are also many examples of more sophisticated subterranean architecture examples in Cappadocia. More refined objects and more difficult to construct were usually built for religious purposes. There are carved in the rock many different sanctuaries corresponding in style with many others built at that time they were created, mostly during the Byzantine period (Pict. 5.31).The biggest subterranean households in Cappadocia are located in Kaymakli and Derinkuyu. They are called subterranean cities, because their sophisticated, multi-functional arrangement looks like an urban site. There are homes, magazines, workshops, workplaces (e.g. a mill, a winery), and chapels. The chambers are located on different storeys (until today, there have been discovered 8 storeys reaching 85m deep inside the rock, but the expectations are greater, for many more of them) (*Wikipedia 2007*). The levels, storeys, are connected with together with stairs, which are also carved in the rock. Mainly top storeys were inhabited, close to the surface. The whole lot of magazines underneath enabled people to store large quantities of water and food. There is pitch-black inside, so they had to use torches. Because of that scientists think that the subterranean cities were used as provisional hiding places for many people, rather than a permanent habitat. The entrance gates were shut with large stone doors from the inside only. Habitants could also secure with similar doors each storey separately. An extended ventilation system provided the caves with fresh air. Water was collected from the magazines and drew from wells in the ground. There are also waste chambers, which were emptied in a suitable time. The city was practically self-sufficient for a long time, where there was no need to go outside. People could contact with each other walking through kilometers of subterranean connecting corridors (*Wikipedia 2007*). Architectonic solutions applied to those cities are of a great interest for many scientists. The details such as stilts, stairs, mezzanines etc. decorated and diversified the whole inhabitable space (Pict. 5.32). The only discomforts are lack of sunlight and visual contact with the surrounding landscape.

There might be found more examples of similar subterranean buildings in many parts of the world, e.g. in Petra, Jordan, where there is the most beautiful subterranean sanctuary hewn in a limestone rock (Pict. 5.33). There are also many households in Spanish city of Guadix, which are also self-sufficiently hewn in rock (Pict. 5.34). The main rock here to carve and hew in is limestone. There might be considered as self-sufficient, hewn in the rock the remains of mines, such as in Wieliczka, Poland, contemporary managed as a museums, health and recreation resort, as well as a sanctuary, still in use.

Picture 5.35: Subterranean habitats in Matera, Italy (Wikipedia 2007)

Picture 5.36: A subterranean house in France (peacham.com)



Picture 5.37: An outline of the structure of a subterranean courtyard habitat in China (Al-Mumin 2001)

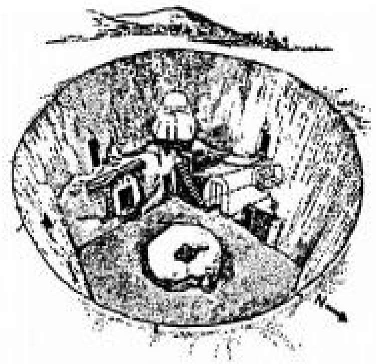
Picture 5.38: A view of one Chinese subterranean habitat (arch.mcgill.ca)

European Subterranean Households: There are to find subterranean households of similar construction in the parts of West Europe, which is rich in limestone. There were hewn in the rock deep chambers, sheltered with a veneer wall. There were some holes in it, regular in shape, to assemble standard windows and doors in. The author named that type of construction 'self-sufficient structures hewn in the rock with the curtain wall'. There were extensions built to the veneer walls: penthouses, or the subterranean habitat was extended with a detached house. The appropriable space was created economically, and their exploitation is cheap (due to the low costs of heating and renovating). The curtain wall creates an aesthetic front wall, according to the stylistics of the time of building, and the investor's wallet. Those houses are well-known in Matera, Italy (Pict.5.35) and Saumur region in France, in vicinity of the Loire river (Pict. 5.36) (Rewerski 1995).

Subterranean Households in China consist of a courtyard and the system of subterranean chambers around it. The author here named them as 'courtyard structures hewn in rock'. The firs structures of thaT type were build in the neolithic era. The remains of courtyard structures hewn in sandstone were discovered in Banpo. Tradition connected with with that kind of subterranean habitats has been performed for a long time. Today, the average amount of such houses is estimated at 40 millions of courtyard subterranean structures hewn in rock in China (Rewerski 1995). They usually consist of a rectangular courtyard of sides 9-13m in length, there are seldom found round courtyards. The courtyard usually is 9m deep. It is enough to keep the house safe from groundwater, even during pouring rains (Al-Mumin 2001). A typical Chinese subterranean household is shown in Pictures 5.37 and 5.38. As it may be seen such a house is regular in shape: rectangular courtyard, long and vaulting residential chambers. The chambers are usually 3x7m and 3m high. There is a separate pit hewn, open to the staircase. It is located parallel to the courtyard and connected with it with a tunnel at the foot of the stairs.

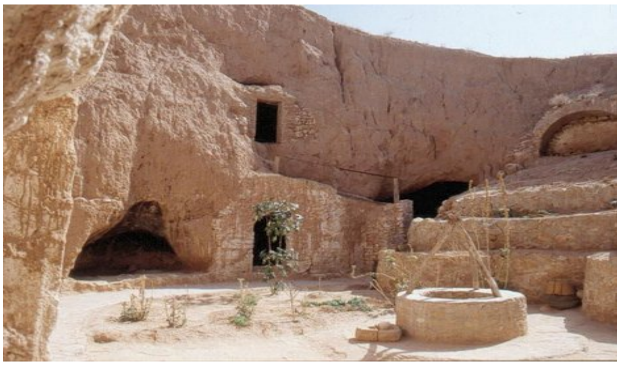
Subterranean Households in Matmat (Tunis) they are also courtyard structures hewn in sandstone. Groups of neighboring households establish villages (Pict. 5.39). Courtyards are usually just pits, 10m deep, on a plan of more or less regular circle, 5-10m in diameter (Pict. 5.40). They are used as inside atria. There might be also gardens on ledges or at the foot of a mountain. Sometimes only a part of of the circuit is corralled with a slope, the rest in walled with a stone fence (Pict. 5.41) (Krarti 1998). The yards are not just empty spaces, but they are used for many things: there might be, close to the house well, some plants cultivation on terraces fields or a place to breed animals. The household's rooms are located quite freely inside the mountain, and their cubature is adapted to the role they perform in the household. Thanks to the fact that the habitats are architecturally individualized, they are quite picturesque. They are very often two-storey houses. Stairs carved out of the rock, or foot-holes cut in the rock itself, leading to the second floor, and sometimes higher (Pict. 5.43). Exploited chambers perform as bedrooms, family rooms and magazines. The rooms are usually 4-5m in width, 8-10m in length and 3m high. Some of the subterranean households were adapted into hotels. A change of the function needed some specific architectonic changes. The rooms are smooth and ovoid in their shape, and not any more the same as well known rectangular forms in typical European buildings. There are carved in the walls shelves and cabinets, and in the floors there are platforms for sofas and seats. The fabric curtains are used as the doors. Matmata is located in the Sahara desert, where there is a dry and hot climate, and that is why the holes in the walls are not covered. Only one entrance leads from the atrium, and this is a ladder at the wall of a slope. It is enough to draw it up to 'close' the door against strangers. Habitats on the slopes are secured with gates in the walls (Pict. 5.41).

Picture 5.39: a bird's eye view of Matmata, Tunisia, with many courtyard subterranean habitats (Temeemi i Harris 2004)



Picture 5.40: An outline of a household with a round courtyard in Matmata, Tunisia (Al-Mumin 2001)

Picture 5.41: A courtyard habitat hewn in the rock, on a slope, partly corralled with a wall with a stone gate in it (omniplan.hu)



Picture 5.42: A multi-functional courtyard: cultivation terraces, a well to draw water in the middle (Matmata, Tunezja)

Picture 5.43: Entrance to the second floor is possible with the foot-holes cut out in rock (A) or stairs carved out in rock (B) (Matmata, Tunis)

There is very hot in the Sahara desert, but the subterranean habitats assure a comfortable temperature in the insides, whole year round, without any need for air-conditioning, so the energy consumption is significantly low. Additionally, to protect the walls against becoming hot they are often painted in white to return as much sun-rays as possible (Pict. 5.43).

Picture 5.44: A house of J. Barnard (Temeemi and Harris 2004)

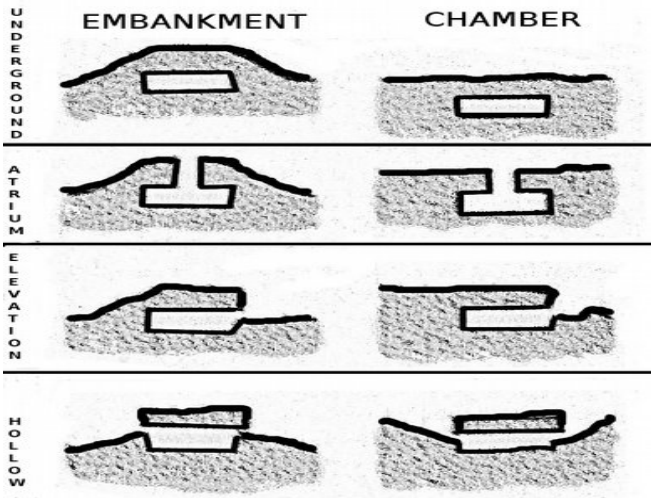
Picture 5.45: A subterranean house in the slope (Pawłowski 2004)

A house of J. Barnard: One of the oldest examples of modern subterranean architecture is the house of an architect, John Barnard, in Osterville, the USA. It was built in 1973 (Pawłowski 2004). It is a spacious summer house of an atrium type. It was built in a depression of the ground, and its roof was coated with 25 cm of the ground. The author recategorized this construction as a subterranean building. Setting the house under the layer of the ground, along with a small atrium, may assure a stable temperature there and shelter the house from winds and noises (Temeemi and Harris 2004). To enter the house one has to go down the stairs to the atrium below first (Pict. 5.44). There are rooms located around the atrium, and their large glass surface lets the light inside the house.

Pawłowski (2004) shows one more subterranean house, one built in a slope (Pict. 5.45), and his own design of a modern, fitting picturesque in the landscape, an underground building (Pict. 5.46). He also encloses a specification of structures of that type built contemporary, depending on the degree and the kind of hiding them under the ground. He distinguishes the embankment type and the chamber type, and they are divided into: a completely subterranean type, an atrium type, an elevation type and a hollow type (Pict. 5.47).

B. Lishman's House: A very interesting example of the subterranean architecture is a habitat, which belong to the architect, Bill Lishman, Purple Hill, the USA. It consists of several big, onion-shaped buildings. Their construction truss is made from reinforced concrete. First, there were built several net wire structures. Next, reinforcement rods were coated with concrete. After they dried, they were covered with ground. There were left exposed the skylights only in the tops of the domes. The insides were painted in white, to let the light to disperse better in the rooms, creating bright, pleasant interiors. The ovoid architectonic form of elements, made to give shape to the interiors, add the house a unique glamor (Pict. 5.48) (Lishman 2007).

Picture 5.46: A project of a subterranean house by Pawłowski (2004)



Picture 5.47: The kinds of subterranean buildings by Pawłowski (2004)

Conclusions for architect

As it seems to be proved above with the whole range of analyzed habitats there are many different means of managing the space of subterranean households. Diversified technological solutions were discovered and improved by different cultures in the whole world. Today, they are appreciated mainly because of their ability to keep temperatures stable and to save energy. Those values are also characteristic for modern subterranean buildings. Although, only subterranean households in rock are strong enough to stay almost intact for ages. There are on Mars some possibilities to inhabit natural depressions in the ground shell or to build inhabitable constructions under the ground. In such dwellings there may be similar conditions to those that there are on Earth, due to almost the same subterranean environment. They should be advantageous in almost the same way. Subterranean habitats on Earth depend on geological structure of the ground: they are located in natural forms of the landscape, or they are hewn in the form of tunnels in rock, which should be easy to mould and durable at the same time, like tuff, sandstone and limestone, or such buildings may be constructed inside deep pits and coated with the ground. As it can be seen, a subterranean Martian base of that type might be located in a chosen spot: there should be caves in there, or there should be easy to mould kind of rock, or where there is a thick layer of granular, adhesive material, similar to the Earth's ground.

Picture 5.48: W. Lishman's house: a bird's eye view (there can be seen only white skylights in the grass), onion-shaped reinforcement rods , the insides of the house (Lishman 2007)

1. The author distinguishes several types of subterranean constructions that might be taken into consideration while designing a Martian base: caves, rock niches with buildings, subterranean households, and structures hewn in rock: self-sufficient, with a curtain wall, and of an atrium type.

2. Subterranean households assure a resistant temperature stability, what benefits in energy savings while heating such a structure. There might be obtained a considerable low energy consumption in such a habitat on Mars, what would considerably lower the costs of exploitation of such a construction, and what follows, lower expenses of the whole mission.
3. There is half the sunlight on Mars in comparison to Earth, so artificial illumination of the insides would be necessary, no matter where located: under or on the ground. In such a case the natural illumination is less important on Mars than it is on Earth.
4. Subterranean habitats on Mars would protect the best their habitants against any outside extreme conditions: winds, dust, storms, whirl-winds, hoarfrost, the Space and Sun radiation.
5. People were able to hew tunnels in easy to mould rock centuries ago. They used primitive tools and technology. That is why it might be suggested that even on Mars it should be a kind of task considerably easy to perform, and at the same time not demanding complicated technologies and heavy vehicles to be sent from Earth.
6. There was water in liquid state million years ago on Mars. It is possible, that there is still some of it, also liquid, deeper under the ground somewhere in Martian shell. It might be suggested that somewhere on Mars there might be some karst caves to find, which Marsonauts could inhabit, in a similar way as many people did on Earth in such places.
7. Taking into consideration geological structure of Mars and its landscape it might be concluded that the most probable to find there depressions in the ground are lava caves. Lava tunnels were inhabited on Earth. Successful simulations of bases in such tunnels can induce one to consider such possibility that future Marsonauts would inhabit similar subterranean tunnels or other constructions of that type as well. A finding of a cave that would be suitable for building a habitat inside and would assure a water reservoir on Mars would be an additional success.
8. Natural tunnels are very durable. Also, anthropomorphic constructions hewn in rock is characterized with the strong durability for a long time. Martian base settled in a local mountain structure, in a natural or artificial opening, may have a chance to stay intact for ages.
9. The sunlight access and an opening to the view of a landscape may bear a great influence on the mood of habitants, and on their psychological comfort. This is a priority in Martian base. Subterranean habitats allow only a limited contact with the surrounding landscape, and so while considering different technological solutions of those types of habitats, this question should be answered. The largest openings are in the rock niches with constructions inside them. They should be airtight on Mars, but there might be used transparent partitions to do the job. The structures might be arranged in a way so as to assure the vicinity of the surface of a slope, where there could be

drilled many wholes to install a curtain wall with many windows in it. What is more, considerably shallow niches hewn in rock might be covered with a curtain wall as well. Subterranean habitats may possess atria, large skylights, transparent roofs, walls. The most difficult problem it to illuminate already existing caves, where the limited access of the sunlight is poor, through the cave's entrance and some hornitos skylights. To improve the comfort of habitants there should be made some more, artificial openings.

10. A settlement of Martian base in an already existing cave is the most economical solution. This is a ready structure that might be occupied straight away. There is no need to construct a truss and there is no need to prepare other building materials. What is more, caves offer the most flexible space, which might be managed differently.

11. There are many cliffs and steep slopes to find among other land formations on Mars. It is possible that there are some inhabitable depressions, where a kind of village would be settled, similar to the Cliff Palace in Mesa Verde. They should be only made airtight, to keep the artificial atmosphere inside.

12. Living under the ground does not mean deprivation people of any creature comforts, or even luxury. Some very interesting solutions of interior design were presented by C. Cabrera and B. Lishman among others.

13. Openings drilled in rock are usually in irregular shapes. Making them according to the planed size and shape needs more work and precise tools. However, it is possible, as wonderfully decorated churches in Cappadocia and Petra prove. There is an alternative solution to the problem: the openings could be made in an easy way, and next, the airtight curtain wall installed, with specifically prepared windows and doors, as it was done in the houses in France or Matera.

14. Large subterranean habitats on Earth need a sophisticated ventilation system, e.g. in Derinkuyu town. There would be LSS on Mars to create and keep the artificial atmosphere, independently of the location of the habitat. Thus, there is no need to build any ventilation systems in the rock, what makes the building job easier.

15. There were hewn tunnels to connect subterranean towns in Cappadocia. Thus, there would be no need for people to leave the safe habitat to go to even to some other places, which would be located far away. In Martian base such tunnels would lead to different points, even to the outside ones, of the habitat: landing pad, garages, magazines, workplaces etc. In future, they would lead comfortably to other villages that might be established on Mars.

16. The atrium structure hewn in rock are the most numerous examples of subterranean habitats. They are independent of the landscape, they might be built on a flat ground, as well as on a slope. The inside courtyard might be managed differently, e.g. as a family meeting place, for cultivation, a place to draw water, to breed animals. This solution seems to be adequate to adapt on

Mars. Habitable chambers would be protected against the Space and Sun radiation with a thick layer of the ground above them, and on all the sides, and the courtyard would create a flexible common place under a transparent cover, installed to obturate the whole habitat. The courtyard would be used for: agriculture, a water reservoir, a gym or a meeting place.

17. The structures hewn in rock might be of different shapes, what gives an architect some opportunity of freedom in planning. There might be ovoid and angular elements in the rock, stilts, mezzanines, stairs, platforms, even some pieces of furniture. Such solutions might be observed in many examples of already existing subterranean habitats on Earth.

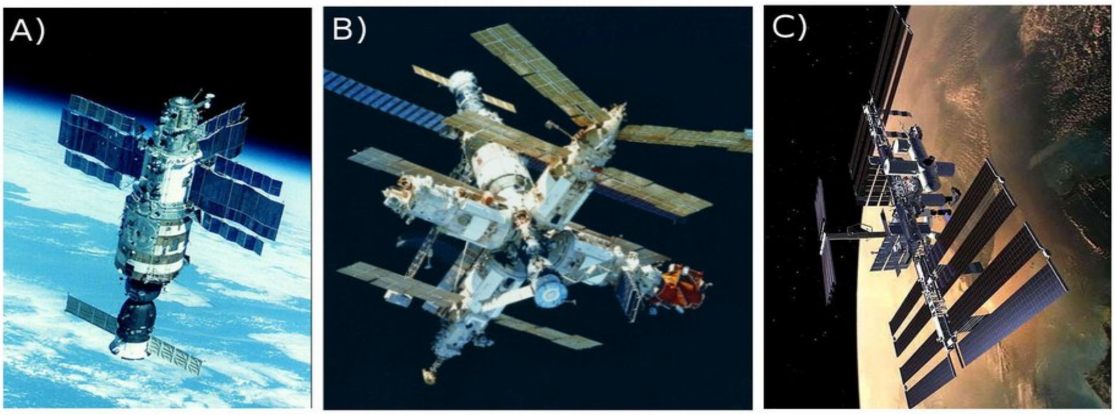
18. The subterranean buildings assure the closest access to the surface if they are open, even partially, at the top, offering large transparent planes, when built shallow in the ground. However, it should be taken into consideration that if the ground on Mars performs as a radiation protection, a thick layer of it is recommended to assure the necessary protection. The coating forms would need some reinforcement, because Martian ground consists mainly of light dust susceptible to wind and easy to blow away. At last, subterranean buildings require a separate truss construction. The ground would perform only as a protection against weather and temperature fluctuations.

19. There are walls and ceilings painted in white to disperse the light and create a brighter atmosphere inside subterranean habitats, and furniture is kept in light, pleasant colors as well. This solution is worth imitating for Martian base.

20. The outside stairs, as in Chinese atrium constructions hewn in rock, allow a safe and comfortable going down to the underground places, without any interference with the habitat's construction or structure. In case of Marian base it would be more efficient to build a separate entrance element. If built, it should be protected against being covered with the dust. The stairs leading straight to the atrium, as in the house of the architect, J. Bernard, would be more difficult to make, if an airtight roof is crucial for Martian base.

5.2 Habitats in the Space

There are suitable conditions to live for a human being on Earth only. The Space is a strange environment, which a human being is not adapted to. However, humans has left Earth and survived in the outer-space in a specifically adapted habitats. Here, there are elaborated some Space habitats , orbital, on the Moon and prototypes of Martian habitat.



Picture 5.49: Orbital stations with Russian habitats: A) Salut, B) Mir, C) ISS (NASA)

5.2.1 Orbital Habitats

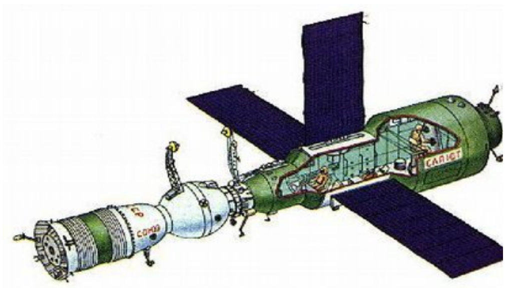
The Space is almost perfectly empty, its density is very low. Temperature is only about -270^{O}C. There is no atmosphere, so no one can breathe there. There is no gravitation, there is nothing to push from to move around. There is nothing, apart the radiation. The Sun Radiation close to Earth is strong enough to heat the sunlit surface of the object floating in the Space to a very high temperature, even up to 200^{O}C. The Space Radiation spread in there in all possible directions, because it originates from different parts of the Galaxy. The Sun Radiation that accompanies the Sun storms, also spread in the Space without being stopped. There are sometimes meteors and micro-meteors. They are incredibly seldom, however they gain so much speed that they can damage easily any object floating in the Space on their way.

As Ashcroft says (1958, p.227): 'if we get in to the emptiness of the Space without any shelter, we would die after a short and painful moment. The air would escape from our lungs, gas dissolved in our blood, and systemic liquids would become gas and push away the cells and creating bubbles in capillary bed, and stop the oxygen from going to the brains, the air blocked in all the internal organs would expand, blowing out the viscera and eardrums, and the intense chill would cause an instant freezing of the body. We would lose our consciousness in less than 15s'.

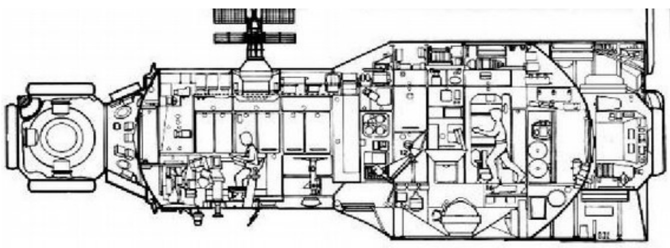
There are two types of the Space habitats: orbital stations and Space Shuttles. They are stiff metal constructions. Orbital stations are single, finished modules sent to the Space alone or in groups of modules sent separately and connected with each other at the orbit. There are one or only a few elements in such a complex, which create the habitat in there. Space Shuttle is a spaceship, which starts from Earth as a part of the rocket, and it lands the same way as common planes do. It is similar to a passenger plane. Its construction, however, is much more sophisticated, and the materials used for building are characterized with an extraordinary resistance. It is also larger in diameter, because there is a great cargo space inside, where the whole orbital equipment and cylindrical laboratory modules are loaded.

Salut: The Russians were first (1971) to send orbital stations to the Space: they were Saluts (Pict. 5.49). There were 7 of them, every one looking almost the same, of the same cubature and weight. The most sophisticated version of it, Salut 7 was 19.8 t heavy. Every stations consisted of two cylinders, firmly connected together: one smaller, the other one—larger. They were from 2–4.15m in diameter, and 13.6–16m long, depending on the type of module. The artificial atmosphere was similar to the Earth's, with its pressure and components. The temperature inside was possible to change, from 15 to 25^{O}C. The was one oblong place for working and living. It was equipped with: places to sleep and to work, laboratory instruments, a toilet, a place to exercise with some sports facilities (walking tract, cycle ergometer), and a shower in a shell. There were 15 portholes in the walls, a special kind of windows to observe the surrounding space. There were three Cosmonauts taking part in one mission. They came in there by a spaceship, Soyuz. It also was used for transportation food there, and to push the orbital station to a higher orbit when it was too close to Earth and there was a danger of burning in the atmosphere. Soyuz docked to the spherical connecting element of the habitat (Pict. 4.50)

Mir: Mir, the habitat of the orbital station, was similar in construction to the previous one. However, the insides here were cleared out of many of the instruments, which were located into other technical modules connected with the habitat and establishing together a multi-functional space-structure (Pict. 5.49B). The designers also took care of the interior design, to influence positively the habitants' psychological comfort. The floor was covered with a dark-green carpet, the walls were painted in light-green and the ceiling—in white, with fluorescent elements. There were separated two tight private cabins on Mir. There was a sleeping bag and a computer work-site in both of them, and there was also a porthole (Pict. 5.51). Every orbital mission took up to several months. A Polish cosmonaut, Miroslaw Hermaszewski, took part in one of them, at the Salut 6 (Marks 1997). The longest one-time stay in the Space took 437 days; it was W. Poljakow who did it. It was an exceptionally difficult psychological experience for him.

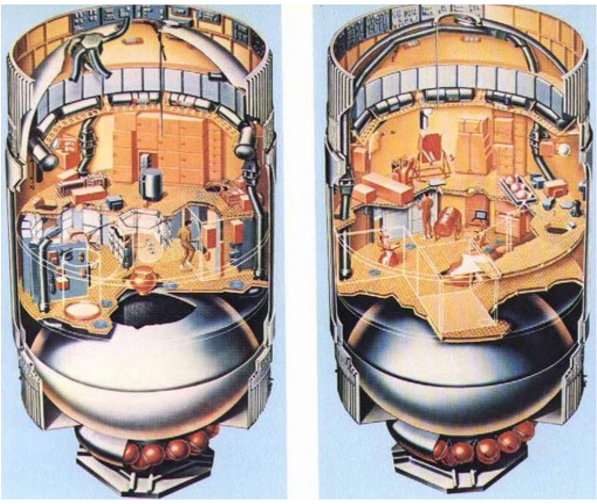


Picture 5.50: A perspective section of the orbital station Salut and the connecting module Soyuz (NASA)



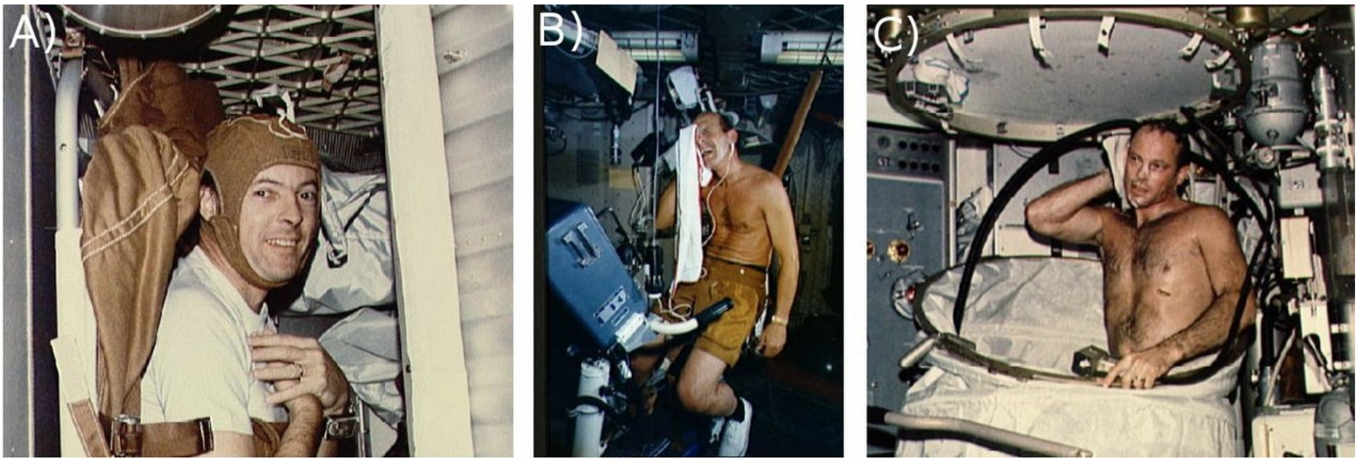
Picture 5.51: A section of the Mir habitat (astronautix.com)

Picture 5.52: The photos of the insides of the ISS habitat (NASA)



Picture 5.53: Skylab in the Space (NASA)

Picture 5.54: Perspective sections of Skylab with a human scale pointed (NASA)



Picture 5.55: The photos of the insides of ISS habitat : A) An astronaut in his sleeping bag; B) exercising on the cycle ergometer; C) having the shower (NASA)

ISS: Contemporary, there is only one orbital station in use, International Space Station, ISS. This is a very sophisticated, multi-modular construction, it has been built since 1998 by 16 countries from all over the world in cooperation (Pict. 5.49C). It consists of over 100 elements. One of them is a habitat called The Star (*Russ. Zwiezda*). It was made in Russia. It was assembled in the same place, where habitats were initially produced, and that is why it is of similar construction. However, the insides are completely different. The modern habitat was cleared out of most of the research's equipment, that was installed in separate modules of the station. Also, most of the laboratory's space was moved out to a separate module. Thus, much more comfortable living space was created. Designers also took care of the interior design, painting the insides with warm, pastel colors (Pict. 5.52). Private cabins are still small, but in general, the psychological comfort there has been improved significantly.

Skylab: This was the first American orbital station (Pict. 5.53). It was sent to the Earth's orbit in 1973. The object was built from the elements left after manned missions to the Moon–elements of Saturn V rocket. Skylab was 35.4t heavy. The insides of a metal cylinder, 6.6m in diameter and 14.6m long, were divided into two. There were the waste collection tank in the lower part, and the habitat in an upper part of Skylab (Pict. 5.54). There were selected two levels; lower, residential part was divided into: a living room with a sleeping part (Pict. 5.55A), a gym (Pict. 5.55B), a hygiene place (Pict. 5.55C), and the mess. The upper part was occupied by laboratory equipment and working places. It was altogether very tight, the residential part was 2m high only. It was airtight, and inside in the rooms established atmosphere was 74% of oxygen and 26% of nitrogen, ant the pressure was 1/3 of the normal one. There were no problems with breathing of such a gas mixture. The inside temperature was $21^{o}C$ (Marks 1997).

Space Shuttle: The Americans decided, after some time, the maintaince of a permanent orbital station is very expensive. It needs maintenance which is connected with transporting spare parts and working under extreme conditions. Additionally, location of the station has to be adjusted every now and then, because its orbit is spiraling down to Earth constantly. The station had to be pushed higher not to let it enter the thick part of atmosphere and burn there, due to the friction. There has been produced the second best orbital station, a spacecraft with a cabin for pilots, a small habitat and a cargo space to take the laboratory and required equipment for the mission's objectives. It was called Space Shuttle (Pict. 5.56). It took off from the spaceport for 1-2 weeks missions, and it came back to an airport, because it could land as a common plane. A laboratory, a Spacelab, was a singular, cylindrical module, 4.18 m in diameter and 2.68 m long, or two such modules, connected firmly. In the Spacelab there were two cabinets with exchangeable drawers containing the equipment and consoles (Pict. 5.57). The equipment was adjusted to each mission separately to realize its objectives. The habitat—Spacehab

—was built in the front part of the Space Shuttle (Pict. 5.56). The upper part of it was adjusted for the pilots. There was a large window, which was welcomed by all the pilots eagerly. The residential part was located in a lower part. It was very tight in there. There were arranged gym facilities and and sleeping bags for the pilots on a piece of place they could use. They shared their meals there (Nowicki and Ziecina 1989). The Picture 5.58 shows the interiors of it.

Picture 5.56: The view of the Space Shuttle with the view of the insides (NASA)

Picture 5.57: The insides of the Spacelab in the Space Shuttle (NASA)

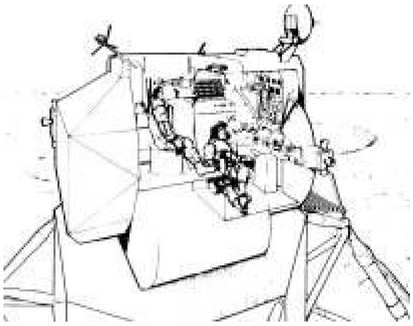
5.2.2 Habitats on The Moon

There is atmosphere on the Moon, but there is so little of it that it creates only a thin layer, just above the surface. There is no breathable atmosphere and there is very cold, the same as in the Space. There is also no layer protecting against the Space and Sun Radaiation, or against UV. There is a mainland on the Moon, but there is no fauna or flora, and no liquid water. This is a waste land, a dessert covered with a layer of sharp dust. Any movement causes the dust to lift high. It is so small, that it can get into the smallest aperture and corners. If it comes into the lung it can irritate them, even hurt them. The gravitation is 1/6 of the Earth's one, what is a consequence of the Moon's small mass. Moving around in those conditions is very difficult, it is easy to fall dawn, and it is very difficult to get up again. The days and nights are very long on this natural Earth's satellite—a day lasts 29.5 of an Earth's day. It is a strange day and night cycle for a human being.

People were able to reach the Moon and conduct some researches there. The first Moon landing took place in 1969. Every mission lasted about 10 days, and the visit on the Moon took several days alone. There were designed small habitats for the astronauts, which made possible for the pilots to work and rest.

Picture 5.58: The pictures of the insides of the Space Shuttle: A) astronauts sleeping B) astronauts sharing a meal (NASA)

Picture 5.59: The Lunar Module of Apollo mission (NASA)



Picture 5.60: Astronauts sleeping in the Apollo LM (NASA)

The Lunar Module: Until now, there was built a Moon habitat for American mission Apollo only. It was called the Lunar Module—LM. It was a two-elements metal module in an irregular shape (Pict. 5.59). The whole construction was 15.3t heavy (Brooks 1979). The module consisted of two main elements: a part to land on the Moon and a part to take off from its surface. The lower part was built as a kind of a platform equipped with four legs to stabilize the object on the landing pad. In the upper part there was a residential and working part for two pilots. Because the pilots were supposed to stay on the Moon for a few days only, the comfort of the habitat had not been taken into consideration very much. The first objective was to lower the costs to the possible minimum, so the habitat was as small as possible. There was one tight common room in the LM with the control consoles and instruments. There were no chairs at the consoles, they were operated by astronauts in a standing position. The astronauts had to sleep in the semi-vertical position, as well, on small, uncomfortable seats (Pict. 5.60). The residential part was about 4m in diameter and 3.5m long.

5.2.3 Martian Habitats

Until now there has not been built any habitats on Mars. However, there were designed four such analogues, and three of them have been built. They are built in strict relevance to the objectives of Martian exploration mission designed by NASA (DRM). The two of them are used for conducting simulations for Mars program on Earth (*Mars on Earth*). They show how a habitat may look like, where the first Marsonauts could live.

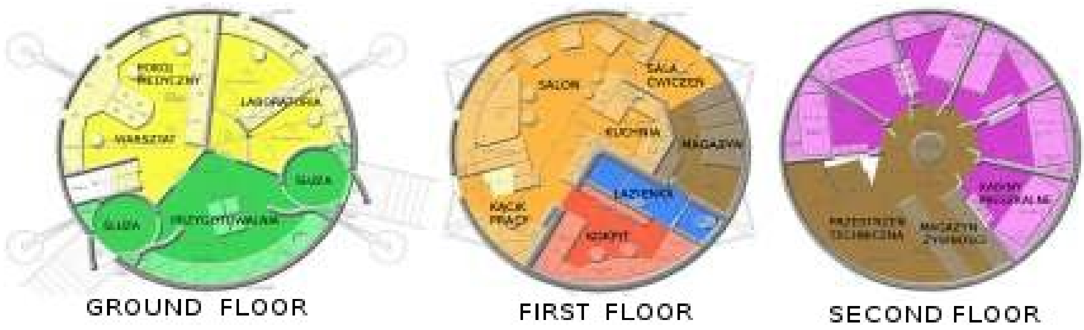
Picture 5.61: The first Martian habitat according to the DRM program (NASA)

DRM Habitat: Due to the NASA model mission concerning manned missions to Mars people should go to the Red Planet for the first time in small metal one-element modules sufficient for a few people only. The first to send would be a return module, which would start producing fuel there, from the hydrogen from the capsule taken along from Earth, and from Martian atmosphere. The next, identical module would be sent with the Marsonauts. The modules are to be connected with a flexible airlock to create a common residential place for the crew (Pict. 5.61). The most probably modules would be in shape of vertical cylinders, about 8m in diameter, and the same height. They would stand on special legs (Hoffman and Kaplan 1997). The originators of Martian NASA program are American scientists, the same people, who created Mars Society. They also started Mars program, Mars Analogue Research Station, of which objectives there were the plans to create four concepts of building the four analogues of Martian modules: two of them American, F-MARS and MDRS, one European—Euro-MARS, and one Australian—MARS-Oz (Mars Society 2007). Every one of them offers a slightly different look of the module and an arrangement of the insides.

Picture 5.62: Martian analogues according to Mars program by Mars Society: A) F-MARS, B) MDRS, C) Euro-MARS, D) MARS-Oz (Mars Society)

Picture 5.63: The insides of the F-MARS (damer.com)

F-MARS (Pict. 5.62A) has been designed by the architect Kurt Micheels. The module is shaped as a vertical cylinder, 8.3m in diameter and 6.45m high. It is build from 12 wall panels, every one 6.1m long and 2.17m wide, and from 12 dome sections converging up in a round element 1m in diameter. The panels are 15cm thick. They are made from glass fiber, honeycombed structured, that is why they are characterized with a strong resistance and they are a very good insulation barrier. The cylinder is propped on six steel legs and stabilized with the six sloping supports. The inside of the F-MARS module was divided into two floors, each one 2.7m high. The lower floor contains a laboratory, a work-shop, magazines, a dressing-room to prepare for going out and an airlock. The upper floor is specified for private cabins and the mess (Pict. 5.63). There are two entrances to the module: the main entrance, and the emergency entrance. There is also a special hatch added. There are two windows at the lower floor, and four at the upper floor. The second American analogue MDRS (Pict. 5.62B) is similar to the first one, F-MARS (Mars Society 2007). There are conducted Martian missions simulations in both of them, and in F-MARS they have been conducted since 2000. Mars Society volunteers spent several consecutive weeks in the analogue, conducting researches on the subject of how to exploit the best the residential part, and what expectations should Marsonauts live up to. It has been shown that people are more comfortable spending the time together, and so they would prefer the common room to be larger. They spent less time in private cabins, and so those could be even smaller. In the common room they spent most of the time together at the table, where they could play, talk, have meals, check maps etc. There is a larger table necessary, or small tables, which could be bring together easily when needed, and in different configurations (Clancey 2001).



Picture 5.64: Plans of the three floors of Euro-MARS, functions defined with colors (Mars Society)

Euro-MARS (Pict. 5.62C) has been designed by the German team of architects, led by Gerhard Dirlich. The European module consists of three floors. There is a working place on the ground floor: a dressing-room with two airlocks, two laboratories, a work-shop and a medic room. There are the common room and recreation room on the middle floor: a mess, a kitchen, a gym, a bathroom and a cockpit. On the upper floor there is a silent zone with private cabins. The magazines were located in two places: on the first and second floor (Pict. 5.54). There were planned two appropriable locks connected with the same dressing-room, what should assure more safety for the exploitation of the habitat. However, what seems strange enough, they located the bathroom hidden behind the cockpit, far away from the private cabins. The analogue is adapted additionally to connect it with a Martian vehicle mpv, designed by the Polish team of engineers from the Technical University in Wroclaw, led by Krzysztof Biernacki[1]. Thanks to such an airlock it is possible to dock an mpv and walk straight into the habitat, without the need of putting on a Martian suit.

The Australian **MARS-OZ** (Pict. 5.62D) has been designed by David Willson. It is shaped as an elongated cylinder with a long nose. It is 12m long, the nose is 6m long; its widest part is 4.5m wide in diameter. The module is propped on four legs and some additional stability is gained with special, additional fastening, stabilizing the whole construction against strong winds. There are two floors inside, each 2.1m high. There are a common room and working places on the upper floor, and private cabins, a toilet and a bathroom on the lower floor. There is one window in each room (Mars Society Australia).

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1 The website of mp v: www.marssociety.h2.pl/old/mpv/index.html.

Conclusions for architect

Habitats, which have been built until now, were all very tight and uncomfortable, based on a minimalistic ergonomic, and not realizing the socio-psychological expectations of people. That is why none of them would serve as a model here, as not able to create a human-friendly Martian habitat. However, the elaborated here, in the section above, examples may help to learn from the mistakes: they show what should be avoided while designing an efficient base. Humble attempts of providing people with better life and work conditions show where an architect can have some leeway to change a tight residential space into the one that would be as minimum depressing as possible. Analysis of Space habitats that have been exploited up till now allow scientists to make assumptions what kind of construction would abide such extreme conditions in the outer-space (Kozicka 2004b). It applies to single small habitats or those connected together in a group.

1. Single metal one-element modules are not suitable for Martian base. They are too tight for space to provide necessary psychological and physical comfort for a long term mission.
2. Metal one-element modules have been used for building all the previous Space habitats. The construction many times has proved resistant and strong enough among all the others, elaborated here, types of construction solutions.
3. In all the previously exploited Space habitats, living-working modules connected with other types of modules with a spherical connecting element. This kind of connection of construction elements has proved itself useful in the Space many times before. Thus, it can be trustful and may be used in plans for Martian base.
4. The rooms considered indispensable in the outer-space habitat are not only residential, working and technical: a mess is essential to share meals for the whole crew, and to spend time together; a dressing-room—to get ready to go out (EVA) with a place for Space suits, an airlock (at least one of them, and it would be safer to plan two of them), and a gym to keep fit in the conditions of lower gravitation.
5. Metal one-element modules might be used for building a base on Mars, and they have to fit in the cargo space of the rockets that would be sent to Mars, and that is why their size and weight have to be limited to stay the same as previous orbital stations (i.e. for as long as there would be larger rockets build in the nearest future). In case of Russian rockets it is an elongated cylinder with a part of a maximum size slightly above 4m in diameter and and about 16m long. In case of American rockets the cargo space can assure a place for a cylindrical module 7m in diameter and almost 15m long. A Space Shuttle can have room for an element slightly above 4m in diameter.
6. The first Space habitats were used only as a shelter for people staying beyond Earth. There was more consideration applied to the socio-psychological problems in time, and the following modules were planned to assure a higher

standard of physical , as well as psychological comfort of the astronauts: separation of a residential place from a working place, introducing private cabins with windows, taking care of colors etc. The importance of life and work quality has been noted. With the help of architectonic tools it was possible to improve the state of being of habitants of the outer-space habitat. At the same time while designing Martian base, the architect should take a stance as for the problem, to make the planning place human-friendly in all possible ways.

7. ISS consists of over 100 elements. It was possible to collect the funds to build such a great Space structure and put it together in the micro-gravitation conditions on the speeding orbital station. If it had been possible to maintain a station in such extreme and difficult conditions, so it should be even easier to manage one on Martian mainland, with larger gravitation. There is a great chance for successful management to build a larger construction. Thus, an architect should not avoid designing a large habitat. At the same time, the easier the construction to manage, the most probable is the correct assembly *in situ*.

8. In Martian base everything should be recycled. However, it is impossible to avoid collecting waste impossible to recycle. It may occupy large space. There was 1/3 of the cylinder adapted for such waste only at the Skylab. There should be taken into consideration magazines for that kind of waste in Martian base, and it would be better if they were segregated. Some of that waste may be recycled, but the process would be economical to perform at times only.

9. While analyzing the architectonic projects of Martian analogues, it can be seen how much work and effort there had been put into managing such a small place, a habitat, to assure human-friendly residential conditions, as well as for working and recreating. It is incredibly difficult to achieve, and this is why there are still some inadequacies to find: tight for space private cabins, a difficult access to the bathroom, recreation place exceptionally limited to a one multi-functional common room, as in the case of F-MARS, or an additional tiny room with one sports device, as in the case of Euro-MARS. In tiny rooms all the elements are sorted out, and it is not possible to move them around, chairs only. So, there is no possibility to introduce any changes into the monotonous, limited life environment. The author thinks that forcing several people to live in such conditions for 2.5 years is unacceptable. There should be at least two bathrooms anticipated, easy to access, and at least two places for recreation, offering more opportunities to spend free time, alone or with the others, including a well equipped gym. An emergency room (ER) should be locked and equipped with the bed for a patient. Private cabins should be larger. Those all things may be achieved in a large base only.

10. It would be a valuable solution to design at least two airlocks, and they both should be connected with the dressing-room serving as a place to get oneself ready to go out. It would be greatly appreciated if one of those airlocks were ready to dock an mpv or other Martian vehicle to enable people to get out of it straight to the base without the need of putting on the Space suits.

11. The most trustworthy are one-element metal modules. They were tested the most thoroughly in outer-space conditions. It is also known that they can be safely connected with each other. A large and safe Martian base might be built just like one given in the example above: one-element metal modules connected together. However, this is also one of the most expensive solutions.
12. People need a large, possibly flexible common room, easy to be adjusted to perform different activities together, what is proved with researches conducted in the F-MARS.

6 Architecture of Martian Base

6.1 Construction

The extreme conditions on Mars limit the choice of kinds of the building technologies that would be exploited to build a base. There were conducted analyses of contemporary accessible building technologies in the following subsections. The requirements to the construction were elaborated in details in the conclusions for architect in section 3.1. There are elaborated here in details those architectonic solutions, which qualify those guidelines, and which seem promising to be adaptable due to the safety and economical requirements on Mars.

In this section there are described following constructions: metal, extensible, carved out, from the regolith and rock, and ice. Wood constructions have not been taken into consideration greatly, because there are no trees on Mars. They are not included in the professional literature, because there is no possibility to grow trees in the artificial environment. Most of the kinds of trees grow slowly and long. There might be some distinguished ones, which grow in a short time: they are bamboo trees. It is suggested here to use bamboo, among other materials, to put the ceiling construction (Petrov 2004).

6.1.1 Fixed constructions from metal and plastic

Previously, all the Space habitats were made as metal constructions. They were many times, and successfully, exploited in the outer-space conditions, and this is why they are considered as the most trustworthy. The largest disadvantage of metal construction is its great mass, and above all, the mass relation to the offered cubature. The heaviest are steel constructions, that is why in case of Space structures steel is substituted with aluminum and titanium–aluminum. The inter-metallic alloys of titanium are the lightest, but at the same time the most expensive, because the technology of their production and industrial treatment is very difficult.

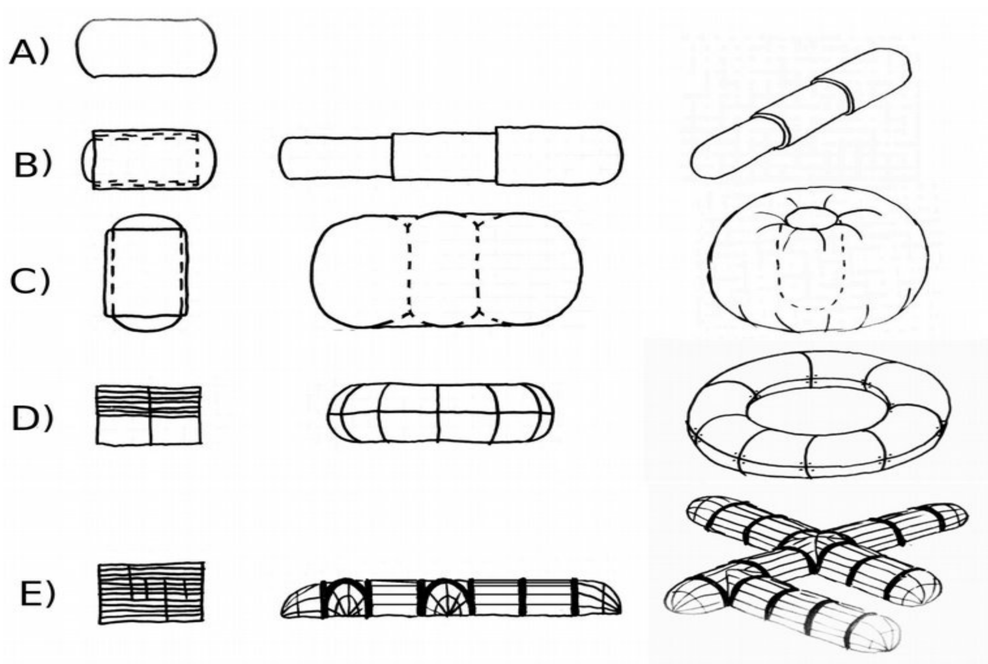
It is possible to produce steel on Mars from the local haematite (Stefanescu and others 1998), with the use of a process very easy to perform (Zubrin and Wagner 1997, p.268). There are popular on Mars also all the needed basic alloy elements to produce steel. WIth choosing the right proportions of those elements, it is possible to obtain any needed kind of carbon steel and stainless steel. The aluminum production could also be performed on Mars, because there is a lot of aluminum. It is, however, difficult to obtain there. Because there is low gravitation on Mars the alloys, which might be produced may be characterized with much better attributes, because during the process their elements may mix better and more homogeneous material is produced (Stefanescu and others 1998). To produce ready metal construction elements on Mars there would be needed to send from Earth a prepared manufacture. The production would by energy consuming, because during the process of melting ore, it must be heated to very high temperatures. Steel could be flat-rolled or cast into different forms of shapes, and drawn into bars. The diversification of metal building materials would enable production of different elements, and even different ready architectonic constructions. What is more, with the unification of screws and bolts for the whole construction, there could be also sent the machines to produce them as well.

SMA is a name of such metal alloys that remember their shape—Shape Memory Alloys. Only some of the alloys are characterized with that, those on the base of copper or nickel, e.g. Ni-Ti, Cu-Zn-Al. Thanks to those SMA characteristics, they would be used on Mars as construction elements, and for the transportation time they could be stored folded, occupying only a part of the cargo space. Those materials, however, are about 100 less strong than steel, so they are not adequate to be used in constructions on Earth. Still, they could be useful on Mars due to its lower, 1/3 of the Earth's, gravitation; e.g. as supportings, inside ceiling constructions etc. There should be performed resistance calculations for each suggested element. The SMA fibers are exploited to make composites of highly appreciated properties of suppressing vibrations. They are being used also, along with metal alloys, to rise their resistance and inflexibility (Yang 2000) . Because of that they could be used for production of metal composites of building materials with good acoustic characteristics.

Nowadays, the plastics which are produced, are of much better resistance characteristics. Composite elements are considerably lighter, and very often similarly (or even more) resistant than metal elements. That is why they would be also effectively exploited for building a firm construction of Martian habitat. The most resistant polymer fibers are produced with modification of polymers and enhanced with the fibers. Polymer modifications lead to production of copolymers, that are of much better characteristics than polymers, which are used for this production. Polymer fibers have a significant influence on polymers mechanical resistance. They are usually fibers: glass, aramid (an aromatic polyamide PA), polyester (PS) and carbon, and also silicon. As Saechtling (2000) notes, silicon fibers are the best ductile materials (9GPa), but at the same time they are the heaviest fibers available. The rest types of fibers reach lower ductility values (up to 4.6 G Pa). The best reliance of their mass to their resistance is characteristic for aramid fibers. They are also fire-proof, effective vibrations suppressors and practically impossible to be punctured (it is why they are used for making bullet proof and resistant to penetration with sharp objects vests). They may be used in very low temperatures. The main field of their exploitation are structured composites of lowered weight used for air and Space industry, as well as for boats and sports accessories production. Their market names are: Kevlar, Nomex and Twaron. Other materials that are used for astronautics as fibers are Vectran (an aromatic LCP) and polybenzoxazole—PBO fibers.

When there are transparent elements or barriers needed, traditional portholes could be installed, or transparent covering elements made from PC would be useful (Zubrin and Wagner 1997, p.241). PC panels may be enhanced with glass fibers to increase their resistance to fracture. To increase their pulverizing and abrasive coefficient of resistance, they are enhanced with PTFE, MoS_2 (molybdenum disulfide) or graphite. PC is used for temperatures to -150^{o}C (Saechtling 2000).

Composite production is theoretically possible on Mars. It is, however, a complicated process and to produce materials of high quality seems rather improbable. Zubrin and Wagner (1997, p.248) are sure, that using polyethylene and propylene (which production from local resources is possible) to produce many different kinds of plastic of diversified characteristics would be highly probable, because they are good materials to make foils, fibers and fixed elements. A specifically planned material could be resistant enough to produce from it fixed elements to build different objects on Mars.



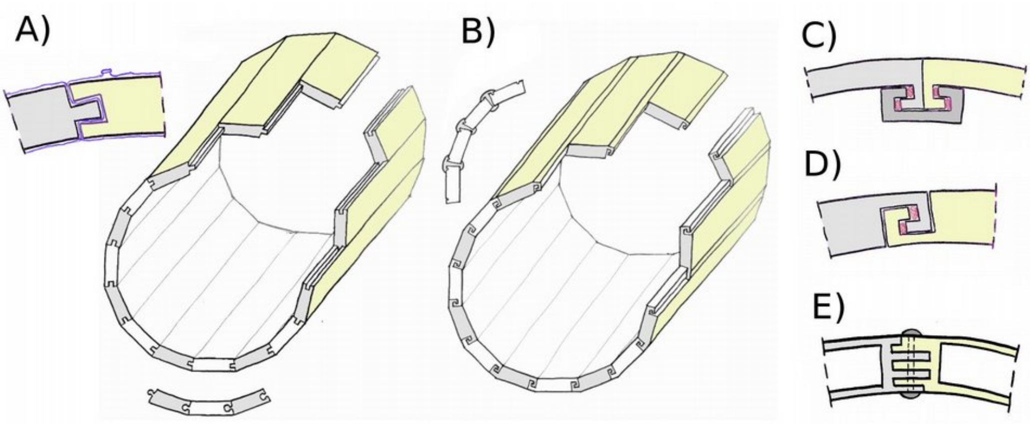
Picture 6.1: Metal constructions plans: packed and after being assembled: A) one-element module , B) detachable module, C) hybrid module, D) assembled multi-element construction, E) skeletal structure construction

Technological solutions

The author here points out five types of fixed constructions that could be a good choice to build a Martian base: one-element modules, detachable modules, hybrid modules, assembled multi-element constructions and skeletal structure constructions.

One-element modules (Pict. 6.1A) are the classic example of previously built Space habitats. That kind of module is a prepared, finished element. It is also completely fixed, rigid. That is why their cubature is limited by the cargo space of amounting rockets. In case of NASA they are 8m in diameter and of similar length, and in case of Russian Space Agency about 4m in diameter and a dozen or so meters in length. Those types of construction offer only limited residential space. However, they are significantly safe: they are resistant to damage and airtight (very good elimination of gas leaks). It may be made sure that everything is precisely prepared, when such a construction is built on Earth, and what is more, before amounting it to the outer-space it may be tested and it can be made sure that the construction behaves according to plans.

Detachable modules in the folded form are of the cubature similar to one-element modules. After detaching them, they hold in their final construction. The methodology of detachment might be planned in different technological solutions. The whole module might be detached, its fragment only, or even some of the elements, when at the same time the whole module is a final prepared construction: all of the elements are connected to keep the airtightness after unfolding, without any additional help. It can be beneficent to the size of the residential space, however until some limitations. There is in the Picture 6.1B) an example of telescopic spreading apart module solution. It consists of three elements of similar length and reduced in diameter elements, to hold as many elements as possible in the largest one. Other solutions are elaborated in the section 6.5.



Picture 6.2: The construction assembled from panels with edges adapted to slip into another one: A) Brzezicki's idea, B), C), D), E) other methods of adapting panel's edges to slide into: the author's concepts (elaborated description in the text)

Hybrid modules are the kind of detachable modules that consist of a fixed metal or plastic part, and the other one built in a different technology. In the Picture 6.1C) there is shown an example solution of connecting the core with an inflatable coat creating a kind of a ring[1]. The construction's cubature before unfolding is the same as of a standard one-element module. The outside unfolding part enables to enlarge the total area of the structure several times.

One-element modules are not large enough, even when unfolded, to become a base. However, they might be connected into a group or a complex to create **connected multi-element construction**. A group of modules creates a total living space several times larger than a separate module. The assembling process takes place *in situ*. The modules may be connected optional, up to their capability or according to the plan designed by the architect.

Assembled multi-element constructions (Pict. 6.1.D) are made from connected panels. The elements are transported from Earth separately, tightly packed in the cargo space of the rocket. The assembling is done *in situ*. After the assembling, the structure is finished, prepared, and removing one of its elements causes damage of the construction. The idea of assembled multi-element constructions brings to the concept of building a large, spacious habitat with an easy use of panels. The method of connecting panels should be easy and effectively assuring the resistance and airtightness of the whole construction.

Marcin Brzezicki (2002) is the author of one of those solutions. The construction elements should have all the ending edges the same to assure an easy way of slipping them one into another, with e.g. tongue and groove joints (Pict. 6.2A). Every panel should stay inside an inflatable coat. After filling up the coat the connections become airtight, when from the inside the pressure of artificial atmosphere would help to keep the construction sealed. To elaborate Brzezicki's idea there would be suggested some other methods of self-sealing connections, as it is shown in the Picture 6.2 B,C, D and E. In C and D examples there were planned gaskets (e.g. as injected sealing foam), and in the E example self-binding tiles are additionally fasten with a screw. Trussing them up additionally with Kevlar thread, inserted through ready holes, would lessen the tension on the panels of gas from the inside of habitat. The rims, sliding bolts, netting etc. would perform similar functions. The assembly of multi-element folding construction would be difficult in Martian environment and there might be required the help of some specific machinery, like a crane.

Skeletal (frame) constructions (Pict. 6.1E) are similar to common constructions built on Earth. The structure is created with a frame truss and an obturating safety coat. The skeleton might be assembled or unfolded: the assembled frame is built from many plain modular elements, which should be connected together *in situ* according to the project; a folded frame is built from many elements prepared and connected in advance with mobile joints that would lessen the cubature of the whole construction for the transportation, and after unfolding it, create a spacious habitat. The skeletal folding structures are

1 The technological solution suggested in TransHabi (see section 6.5).

exceptionally easier and faster to mount, but they have to be planned ergonomically and logically, and assembled precisely according to the plan. The skeleton should create a streamlined construction, and that is why they should be planned as a Fuller's dome, made from rod elements, or cuts of the cylinder in a shape of an arch-ribs. The difficulty of assembling would depend on the project, e.g. a dome would be rather difficult, but a rib-construction as a cut of cylinder would be much easier to mount. The fixed coating should assure its complete airtightness.

Conclusions for architect

Metal constructions are very resistant and trustworthy, because they proved useful many times as different Space structures, e.g. habitats. Because of that, it would be recommended to use them to design Martian base: to build the whole construction, or some elements of it.

1. One-element modules could work as containers to transport other elements, like assembling constructions, amounting to Mars. After being unloaded, they could be used as airlocks with the entrances to the surface, or connections between larger structures, as well as shelters, technical rooms, bathrooms, elevators. Those modules might be also connected together to build a larger complex.
2. There are portholes in metal constructions working as windows. The way of installing the doors may imitate the previously exploited solutions from the Space habitats.
3. Fixed constructions in the form a horizontal cylinder or a sphere need to be stabilized, e.g. in a form of legs on their sides, so as not to let them to roll.
4. The assembly of unfolded modules should be mechanical.
5. Multi-element assembled constructions should be as easy as possible to mount. The elements should be designed to connect them easy together as a one, airtight construction. The parts of such a construction should be of a cubature fitting into the cargo space of the amounting rocket. The weight of a singular element might be considerably large because of the 1/3 of gravitation on Mars, which enables moving heavy objects there.
6. The skeleton structures may imitate their Earth's prototypes. There are many different sources of inspiration. However, a streamlined form is highly recommended.
7. Exploitation of local sources as building materials is recommended, and while planning this, there should be suggested modular metal elements of the easiest construction.
8. Metal constructions might be optionally painted. Also, plastics are easy to apply color onto them, or to be covered with colored foil. Well planned colors would enhance the aesthetics of habitat significantly.

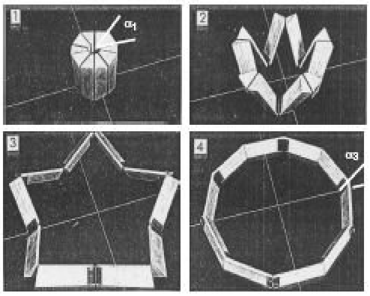
6.1.2 Expandable constructions

Expandable constructions are such constructions, which cubature may be expanded or reduced. The name of this kind of constructions originates in English language. The author has in mind here such constructions, as: folding structures, inflatable structures, inflatable rigidizable structures and shape memory structures. Expandable structures are different from the traditional ones in such a way, that when after being expanded they create ready structures, which might be repetitively folded and expanded easily. After being folded such a structure can fit into a tight cargo space and then they are easy to be transported, and still, their cubature is significantly larger then other constructions. Those constructions are exceptionally light and their mass relation their to cubature is low. That is why they are recommended in the astronautics.

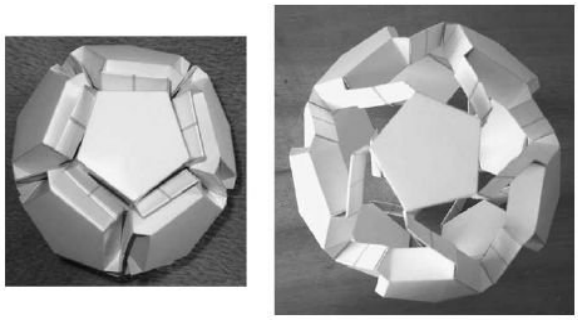
Technological solutions

Expandable structures: Expandable structures are multi-element structures. They are created with rigid rod elements, and sometimes with multilateral elements (Kovacs and others 2004), made from plastic or metal. They are connected together with simple joints. It enables the process of folding and unfolding of the whole construction to be very easy (Pict. 6.7). Those elements may come closer to each other or away from each other, similar to how scissors work. Some of the joints, critical for the whole structure, may be rigid. Because of those joints the whole structure may hold its shape e.g. a sphere (Hoberman 1991a). By creating different configurations of rods and multilateral elements with mobile and rigid joints there might be built diversified folding flat and structured constructions: circles, squares, spheres, domes, curtains, partitions, tents, carports and many others. The examples are shown in the Pict. 6.3, 6.4, 6.5, 6.6, 6.8 and 6.9. After being unfolded, the constructions are rigid and resistant. They might be coated with panels, nettings, fabrics or foils. They would be used for building a whole building of the base on Mars, or modules to build one. They could be also planned to build ceiling constructions, substrings, poles, walls and even furniture.

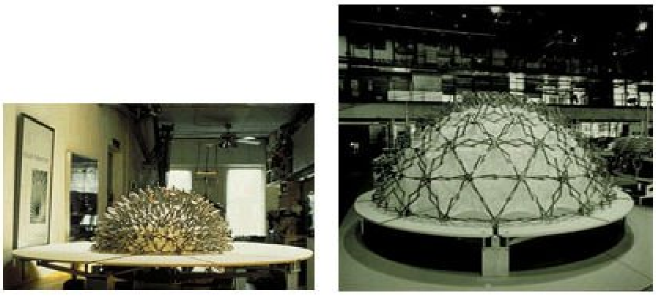
The constructions made from rod elements create only folding truss structures. The architect, creator of many interesting solutions is Chuck Hoberman. The best known folding truss structure is Hoberman sphere (also produced as a toy), shown in the Pict. 6.9. It can expand (or lessen) to five times of its original size. The largest realization of the sphere is 22m high expanding Hoberman curtain Arch built on the platform of Olympic Medal Plaza for the winter Olympic Games 2002 in Salt Lake City. The curtain has transparent panels, which might be lit attractively.



Picture 6.3: Folding multilateral element (Hedgepeth)



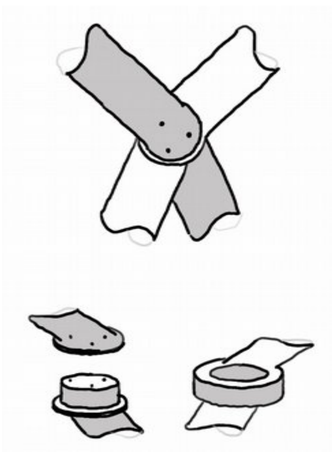
Picture 6.4: A cartoon model of folding sphere built from multilateral and rod elements (Hedgepeth)



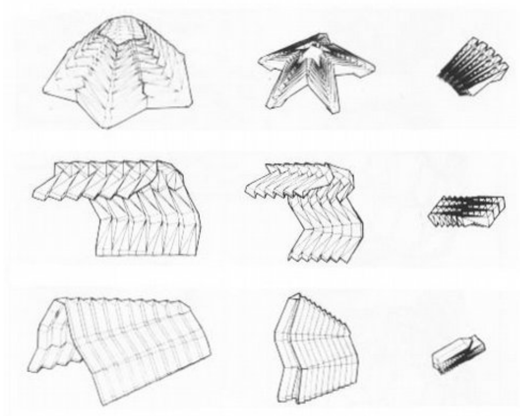
Picture 6.5: Expandable Hoberman Dome (Hoberman Associates)

Picture 6.6: Hoberman Arch (Wikipedia)

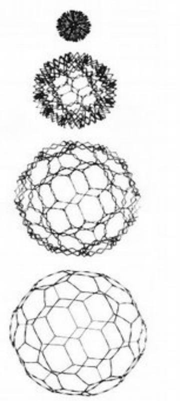
John Hedgepeth is the architect, who created many different solutions exploited in astronautics by NASA. His structures usually fold to small size forms, what results with significant costs savings as for the need of cargo space. Picture 6.10 shows the steps of unfolding the module of the Sun aerial, designed to use the Space Shuttle crane to mount it. The aerial is, according to the plans, 400m in diameter and it is built from folding elements connected together (Hedgepeth and Miller 1987).



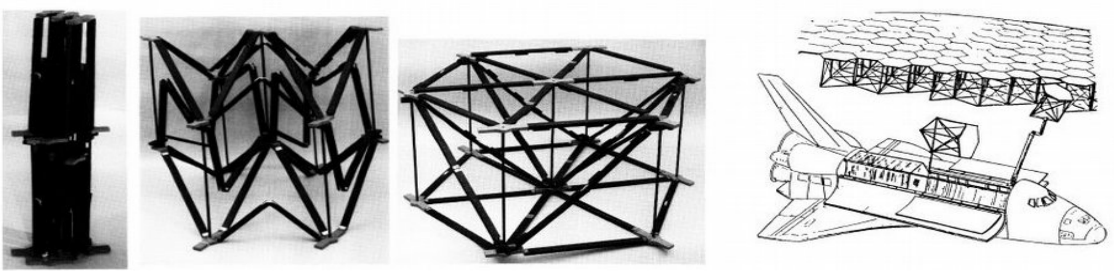
Picture 6.7: Connecting joint of folding structures



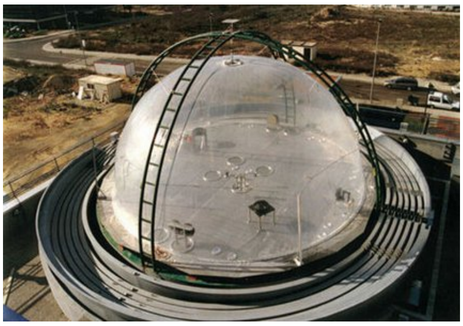
Picture 6.8: Tent, folding structure (Hoberman 1991b)



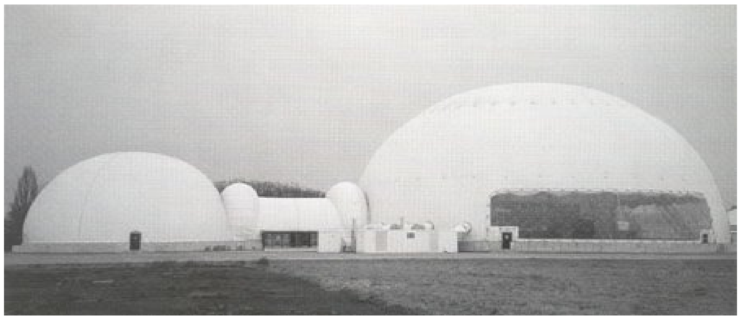
Picture 6.9: Hoberman sphere (1991b)



Picture 6.10: The folding module of the Sun aerial, designed to use the Space Shuttle crane to mount it. (Hedgepeth and Miller 1987)



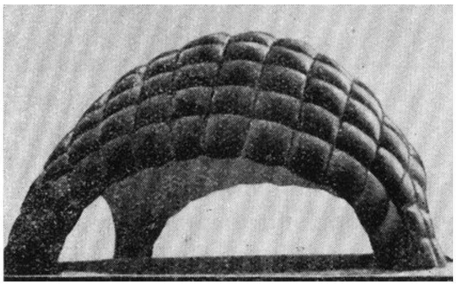
Picture 6.11: EUPHORE Laboratory in the shape of dome, made from transparent Teflon, 9.2 m in diameter (Foiltec)



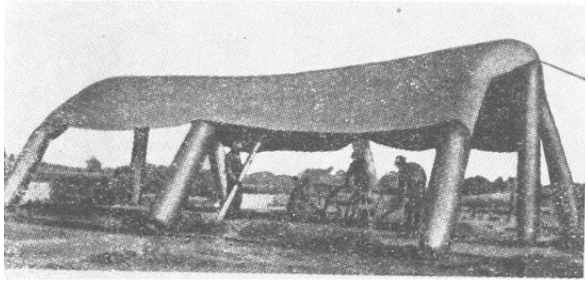
Picture 6.12: ZDF inflatable pavillion, Mediadrom, the larger dome is 51 m in diameter (Schock 1997)

Inflatable constructions: There are three types of inflatable constructions: with the inflatable living space inside, inflatable covers, and inflatable rib-constructions (Tarczewski 1965). The first type seems to be the most sufficient solution for Martian base, because inflating the construction serves its mounting and creating artificial atmosphere inside at the same time.

Picture 6.13: ICSID Congress pneumatic city in Ibiza (Muire 1971) A) view, B) plan



Picture 6.14: Inflatable multi-air-bag cover (type II) (Tarczewski)



Picture 6.15: An inflatable rib-construction magazine (type III) (Tarczewski)

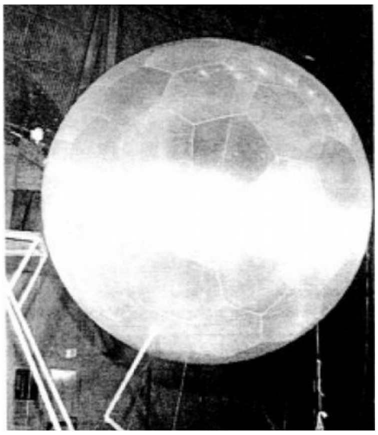
Picture 6.16: An inflatable display pavillion made from inflatable bar and pole truss elements

Picture 6.17: Eden Project: metal construction with inflatable panels (Eden Project Ltd.)

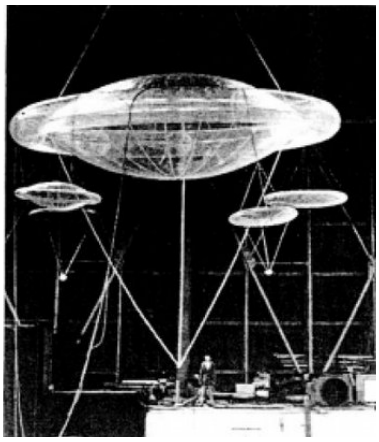
The next two types might be used on Mars to build some helpful constructions: a supporting of the main truss construction, magazines, garages (without artificial atmosphere). The examples of those constructions of type I show Pictures: 6.11, 6.12 and 6.13, type II: 6.14, and type III: 6.15 and 6.16.

For inflatable constructions there are used coatings made from different materials. Usually, they are fabrics (natural or artificial), covered fabrics or foils (Schock 1997, p. 11). The membranes might be transparent, translucent or matte. The fabrics are usually vulnerable to different environmental conditions, so the most often they are coated and made from plastic fibers and synthetic resins. The standard polyester fabric is covered on both sides with PCV, which is needed to protect the fabric against UV radiation, humidity and fire. To protect the fabric against dirt, a layer of an acrylic paint or PVDF is required. Other popular membranes are glass fiber fabrics coated with PTFE or PVC, which are characterized with higher resistance. In the Space constructions there are used the best quality of high-resistant membranes, working well in extreme temperature conditions, and very resistant to puncturing and stretching. There are tested fiber composites from glass, carbon, nylon, Vectran, Kevlar, Nomex and mylar[2] for specific usage (Geoffrey 1998), which are covered with synthetic resins, e.g. PE, PI.

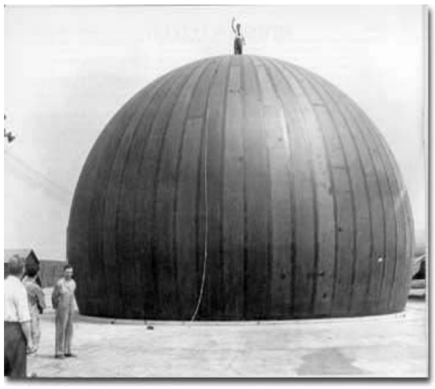
2 For example: Vectran was used for making parachutes of Martian vehicles Opportunity and Spirit, and it was the building material for the prototype of the orbital hotel – Genesis. Mylar was used for the making of the Space balloon shell Echol that would function as an radio receiver on the Earth's orbit. In the Space module TransHab the shell was designed on the basis of Kevlar fibers.



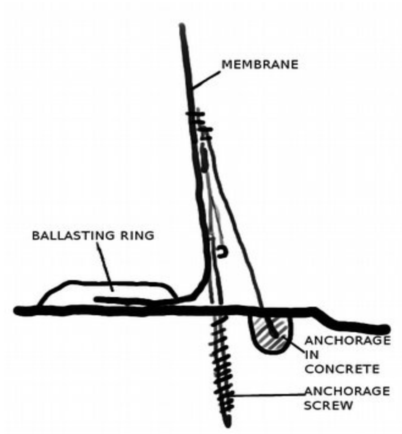
Picture 6.18: Radar Calibration Sphere (Freeland and others 1998)



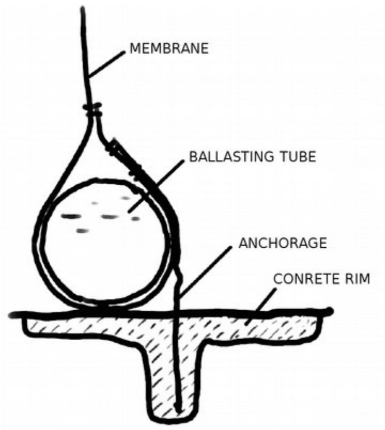
Picture 6.19: Lenticular Inflatable Parabolic Reflector (Freeland and others 1998)



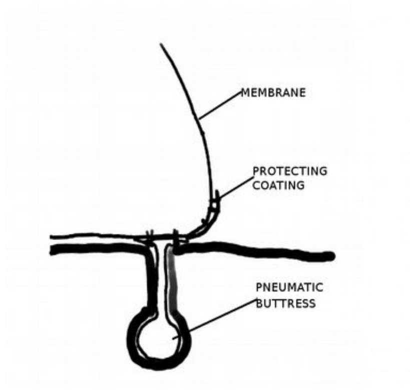
Picture 6.20: Birdair Dome made of longitudinal straps (birdair.com)



Picture 6.21: Linear anchorage of membrane with steel screws and ballasting ring



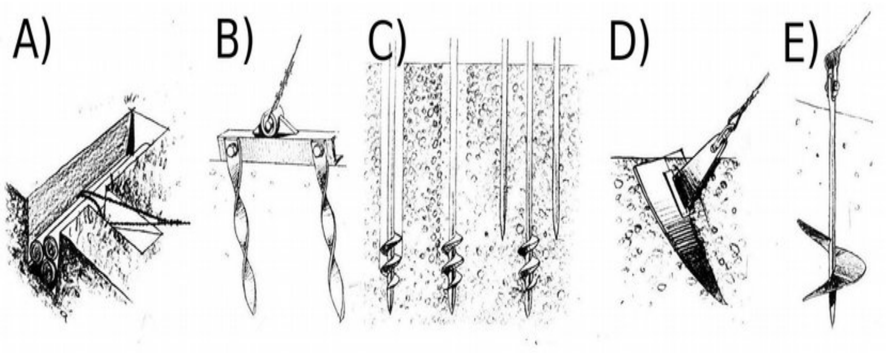
Picture 6.22: Membrane ballasting with soft peripheral tube



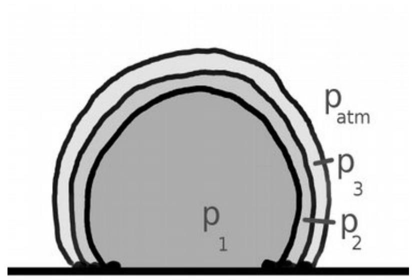
Picture 6.23: Pneumatic buttress

In the Earth's inflatable architecture foil is seldom used, because it is expensive and less resistant to damage than covered fabrics. The most often in use are air-bags with ETFE (Pict. 6.17). They are transparent, considerably resistant, and they are characteristic for a low build-in energy (Robinson-Gayle and others 2001). They are used instead of windows, however, the whole structures could be built from that material. For inflatable constructions on Earth there are also used successfully FEP foils (Pict. 6.11). In the astronautics the most popular now is PI (Moore and McGee 2001).

Larger inflatable architectonic constructions cannot be made from one-element plates, because there are no such large production lines. They should be made of smaller lobes, and next connected with each other. The lobes should be precisely designed to create the suitable final structure. There could be many different solutions as about the number and shape of lobes. The more lobes are designed the easier they are to cut out and create more sophisticated structures. However, less number of lobes means less number of bonds, which are the most sensitive points in the structure. Any defect of a bonding place may be the cause of losing the airtight conditions and disband the structure. However, in case of perforation of the plate, it is best to replace the element with a new one. When the quality of bonds of the membrane is assured, it should be recommended to design many smaller plates, as they are easier to replace. According to the type of fabric there are different types of bonds: sewing (fabrics), gluing (fabrics, foils), welding (foils) and riveting (multi-layer membranes) (Tarczewski 1965). Bonding places are usually visible, that is why the shapes of plates influence the whole aesthetics of the construction.



Picture 6.24: Different types of anchoring elements for inflatable constructions: A) ditch ballasting anchorage, B) twisted steel plate anchorage, C) screw stilt anchorage, D) buoyant slab anchorage, E) screw stilt (Gyula 1977)



Picture 6.25: Multi-layer dome from air-bags with decreasing atmospheric pressure: p 1 >p 2 >p 3 >p atm

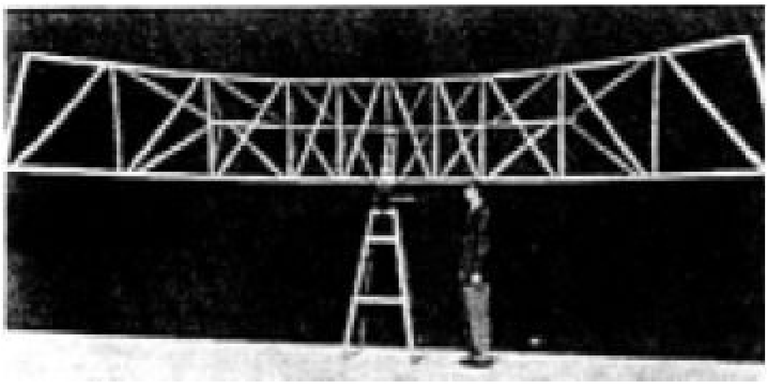
Radar Calibration Sphere Goodyear is made from regular hexagonal lobes (Pict. 6.18), and Lenticular Inflatable Parabolic Reflector, also by Goodyear, is made from a row of chocks on the rectangular mainstay (Pict. 6.19). The Birdair Dome is made from longitudinal straps (Pict. 6.20).

Inflatable construction foundation is achieved by anchoring or ballasting in the ground specific parts of it (Tarczewski 1965, p.65). Anchoring is accomplished by attaching the construction with peripheral anchoring elements inserted steadily or periodically into the ground. In case of steadily inserted elements, there should be more anchorages, but they might be smaller and thrust not as deep into the ground as in the second case. When there are periodically inserted anchorage elements, they should be larger and thrust deeper into the ground, however, there could be less number of them. It should be enough to thrust such elements into the hard basalt layer on Mars, and later, alternatively, to caulk them with resin. The membrane could be attached to the anchorages straightforward, or with a net-layer on the construction attached to the anchoring elements. Such a net should be made of durable tightropes, e.g. Kevlar, as they are even five time more flexible in comparison to steel ropes, and they are very difficult to cut (DuPont 2007). To avoid hovering of the construction, an encumbrance ring should be applied, as it is shown in Pict. 6.21. There could be also a purpose-objected ferro-concrete, or made from steel elements, peripheral belt (Pict. 6.22). It is durable, however more complicated to perform on Mars. The ballasting may be achieved by coiling the lower part of the membrane around the tube (this part of membrane could be made from water-proof fabric), where the tube could be filled with a heavy material, e.g. water or, as the author here suggests, rock pieces (on Mars it would be acquired straightforward from Martian surface regolith).

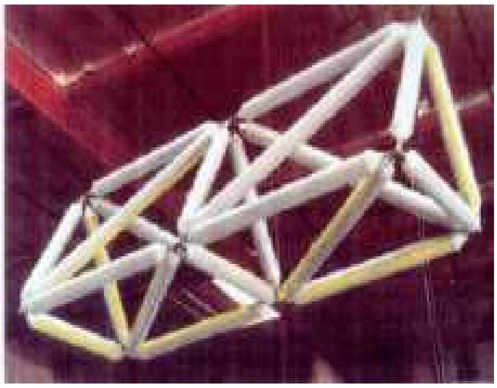
Inflatable constructions are exceptionally light and easy to fold. However, their deployment requires heavy, forced airflow station. To mitigate significantly the weight of the equipment transported to Mars, the ballasting foundation achieved by the use of tubes filled with the regolith should be rather recommended on Mars. The author here is fairly sure that anchorage could be made with the use of pneumatic foundation. There could be also taken into consideration small membrane elements, inserted into the ground in small slots drilled in the hard surface, and pumped up, as it is shown in Pict. 6.23. There are different types of anchoring elements described by Gyula (1977) (Pict. 6.24). Zubrin and Wagner (1997, s.243) suggest that the inflatable construction could be supported with-in the ground; first, there should be prepared an indentation in the ground, the construction should be put in place in it, and next the lower part of the streamlined construction should be filled with regolith. This would require some huge ground-works in the spot, however, the inflatable construction should be firm, and the regolith inside would be used to grow plants or for other purposes.

Inside Martian habitat the pressure of atmosphere should be kept slightly higher than it is on the outside, to allow people to breath freely. At the same time, it would be supporting the rigid and firm inflatable construction, after filling it with the right atmosphere. However, the Red Planet's atmosphere is very thin, and in the insides of habitat it should be much thicker, so the membrane should be made from a very durable fabric. The author here can see that the structure could be also multi-layer, where between the separate layers atmosphere of lower pressure could be pumped up. Separate layers would be subjected to lower atmospheric pressure (Pict. 6.25).

Inflatable rigidizable constructions: they are multi-dimensional trusses, assembled with slim tube elements. The rods of such a truss could be made from adequately prepared one-element system, as it is shown in Pict. 6.26. Truss assembled with many separate tubular rods, connected firmly with adequate connectors is considered, however, to be safer and more rigid (Pict. 6.27). Every tubular rod may differ in its length, diameter and width. Geoffrey (1998) writes, that the smaller diameter of the rods, the higher durability of the construction to pressing and crushing. It is accompanied by the rise of durability to its mass. Its durability to pressing and crushing also rises when the construction is wider (the foundation rods are longer). To create this, there may be used open cellular foam, flexible kapton aluminum laminate, or hydrogenate resin. Rod elements could be entirely made from open cellular foam, which expands when heated.



Pict. 6.26: Inflatable Search Radar (Goodyear)



Pict. 6.27: Inflatable truss with connectors (L'Garde)

An expanded element made from open cellular foam after cooling becomes firm and rigid (there is more about it in the part treating about constructions made from shape memory materials). Flexible laminate made from aluminum foil, and with kapton[3] coating, it was considered very useful for a long time by different scientists, as to be fully effective with such a thin coating, which is enough to create a rigid construction (about 130 microns). In such a case it adds up very little to the final mass of the whole construction. However, such a thin kapton coating assures not enough durability to pressing or crushing (Lou and Feria 1998). Thus, as the author thinks, inflatable trusses made from kapton aluminum laminate could be of use on Mars only when they should be exposed to stretching tension only, e.g. as a case pressing stone-masonry (see Chapter 6.1.4) or inflatable (see above) base module filled with artificial atmosphere. To build tubular rods of the inflatable truss there could be also used fabric made from durable fibers, e.g. Carbon-fiber, fiber glass, nylon, Kevlar etc. (Geoffrey 1998). The rigid effect is created by impregnation the fiber with adequate resin. Freeland and others (1998) list different types of resins, which could be used for such types of constructions. They are resins indurating under the influence of: water evaporating, heating, cooling, and UV or infra-red contamination. Most of them could be used on Mars. In L'Garde Inc. laboratories there were conducted many examinations to try the most profitable composite of fabric and resin to use in the Space. It turned out that the most optimal solution is the composite made of graphite fibers with hydrogel (Geoffrey 1998, Lou and Feria 1998). For Martian environment precisely there could be specified another type of composite.

In L'Garde Inc. laboratories there was a modular inflatable truss worked out with the use of such types of connectors (Geoffrey 1998). Here, the length of the rods was specified (150 cm). It is also possible to make rods of different dimensions (with the use of similar connectors). However, it is crucial to take into consideration that all of the dimensions have their significant influence on the stability of the whole structure.

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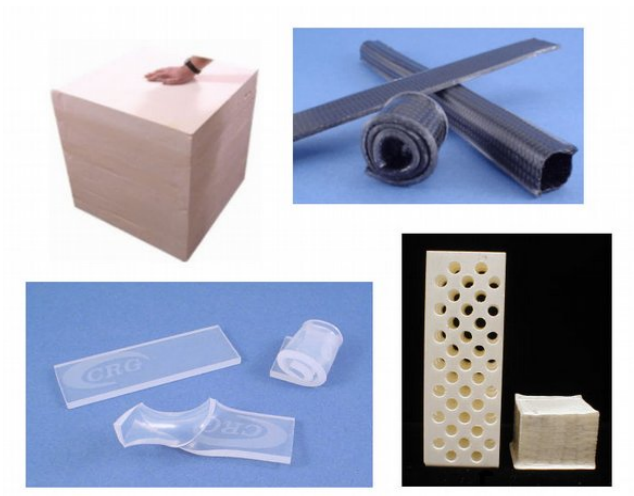
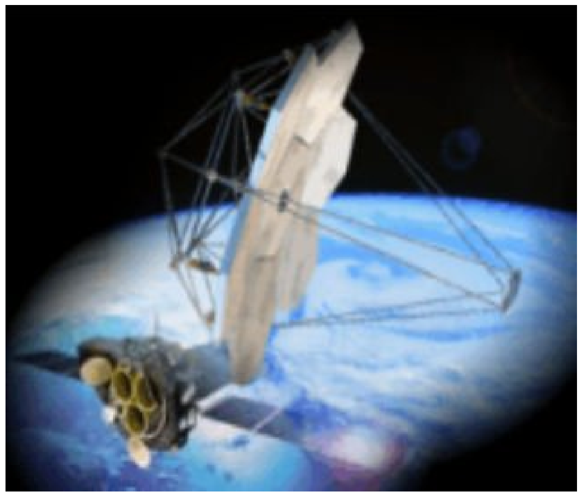
3 Kapton – a thin polyimide coating made by DuPont; it characterizes of exceptional properties in case of durability and insulation, mechanical and thermal conductivity etc.

Shape Memory Polymers: SMP are the polymers with the shape memory. They are exclusively light materials of some extraordinary properties. They are to find in two types of condition: as an expandable, flexible material similar to rubber, or as a hyaloid, firm, durable, hard material (Sokolowski and Hayashi 2003). The transgression from one state to the other takes place at a specific temperature, the so-called transgression temperature (T_g). It is possible to achieve in such a process materials easy to change in very high temperatures, as well as in cryogenic environment (CRG 2007). SMP is modeled in a temperature above the $T_{g.}$ It is then, when it is modeled to the specified form (target form). This material is easy to cut and change. It is attainable as foam, plastic and resin. SMP might be designed in different forms: as sheets, blocks, perforated elements, or in a form of honeycombs, lens and mirrors (Pict. 6.28, 6.29).



Picture 6.28: SMP products (CRG Inc.)



Picture 6.29: Space antenna made from optical elements SMP (CRG Inc.)

The once modeled form is remembered by the material. During the time it is kept in the temperature above T_g , it is flexible and might be bend, twisted, folded, rolled and pressed. The bulk of packed and pressed elements might be reduced even four times. When cooled, it may keep its form as a folded package (it is called hibernation). The storing time is not limited. When it is heated above T_g, it unfolds by itself and stays in the previously modeled target shape. Such unfolded element might be stiffen by cooling, and they become a hard, mechanically durable elements ready to use, as it was specified in advance. The cooling and heating processes might be repeated many times without the effect of weariness of the material. SMP characteristics are: high impact durability (it effectively absorbs the impact energy), very good thermal insulation, low electrical conduction, and radiation invulnerability. This material also behaves well when subjected to overloading (it appears while launching rockets). SMP might be reinforced with fibers (e.g. carbon fibers) to gain higher durability of the material (CRG 2007). This composite might be cut with laser and machines. Some examples of its application there are given as following: rocket hulls, space structures, architectonic materials, sports articles, etc. DARPA and NASA laboratories have been working on SMP application to space constructions (Lin and others 2006).

Martian base could be build from such SMP elements, which could be packed and folded for the transportation purposes and kept in hibernation. After reaching its destination it would be heated to deploy, and next cooled to stay in its specified form. Such a solution has its drawbacks: their deployment requires energy for the heating process. However, the transgression temperature could be designed at a lower level, and such elements could be heated on Mars with mirrors focusing sun rays, to lower energy consumption and expenses for the whole process.

SMP might be used differently in the architectural design of Martian base: as habitat modules, cantilever elements and constructions, window elements, elements focusing light to lit the insides of the base, airlocks, repair-sheds, furniture, household equipment, decoration elements, insulation layers, electro insulation membranes, containers, boxes etc.

Conclusions for architect

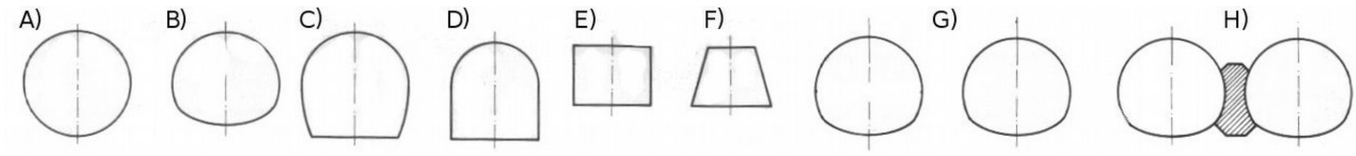
Expandable constructions are light, and they might be folded easily into small packages. That is why they are the most profitable building structures, which may be transported from Earth to Mars. Their assembly requires almost no specialists and the process is easy. The whole process could be fully mechanized. Such constructions were tested in the Space many times. They might be used in many different ways on Mars while building base, thanks to theirs unique properties: as a truss, falsework, or indoors elements.

1. Inflatable constructions (air-filled) achieve only streamlined shapes. They might be eliminated for the sake of traditional cuboid shapes by the division of the space into smaller modules. There might be introduced also firm elements to form their flexible structure.
2. Expandable constructions are mainly truss structures, which require covers such as panels or coats.
3. Use of transparent or translucent coats and panels may significantly influence the positive reception of the general aesthetics of base construction. Such solutions enable the daylight to reach the insides of the base, and during the night time, a lit building might be easy to spot for the returning crew. There could be achieved some interesting light effects on the membranes, which could help to create some variety in the insides of the habitat.
4. Expandable constructions are light, and they may be repeatedly folded and unfolded fast and easy. That is why they are excellent to create flexible insides, satisfying the variable expectations of the habitants of the base.

5. Inflatable structures are the most effective types of expandable constructions, which could be transported from Earth. Light and easy to pack tight membranes occupy little luggage space in the rocket, and later after their deployment, they offer a considerable huge habitable space. In case of failure during landing of the transportation rocket they is not sensitive to damage, as they are not easy to crush, but flexible, and partially expandable (Kozicka 2004c).
6. Expandable constructions may achieve relatively huge dimensions (the diameter of the big dome of Mediadrom reaches more than 50 m!).
7. The method of designing coatings elements for expandable constructions—the sheets of materials—influences the building's aesthetics, mostly when they are transparent and translucent.
8. The safety of inflatable constructions might achieve higher levels, with a help of additional structure preventing the main structure from folding by itself, such as: tying net, external or rigid trabeated, or rib construction.
9. Inflatable constructions require ground anchorage and ballasting, mainly on the perimeter. Foundations made from pressed Martian regolith to the level of floor inside the streamlined structure ensures the optimal dispersion of the coating tensions and an excellent stability on the ground.
10. Expandable constructions may be found useful as division elements of interiors of the base, e.g. as division walls, ceilings, mezzanines, fences, railing etc.
11. Expandable constructions are very durable. There should be remembered that the pressure difference, which the buildings there would be subjected to, might be very high. The difference must be taken into serious consideration at the stage of designing the structure, to make sure it can easily abide those tensions. The overlays should be made from very flexible and expandable materials. The places of connections should be also carefully planned to ensure their safety. The problem could be partially avoided by the use of overlapping coating of several layers. The gas under lessening pressure (starting from the inside coat) could be pumped in between the coatings (Pict. 6.25).

6.1.3 Drilled constructions

Drilled constructions are in the mining industry called *excavations*. An excavation is an uncovering made in the ground, achieved during the process of mining in the rock mass. In case of building Martian base it becomes an architectural form, because it is made to serve as a habitat. There are two main types of excavations: *surface* and *sub-surface*. The surface excavation is the uncovering of rock mass. The sub-surface of excavation is an empty space drilled in the rock mass, surrounded by the rock mass (Tyberia 2007). The sub-surface excavation might be done in several different shapes: as a tunnel, a mine-shaft, a cave.



Picture 6.30: Typical cross-sections of mining excavations A-F, and G and H show parallel excavations (Müller-Salzburg 1978)

The cross-sections of excavations may differ. Their profile is dictated by the geological and mining circumferences, and the need for specific shape of the habitat space. Typical shapes are shown in the outlines in the Pict. 6.30. The circular cross-section (A) is the most characteristic for the mine-shafts. Excavations E and F requires necessarily some construction reinforcement, thus, they are not the best solution for Martian base, where rather streamlined shapes should be required. The cross-sections C and D seems to be the most adequate for such purpose. In case of parallel excavations, there should be kept a safe distance between them (G), or a connecting element would be required (H), usually made from reinforced concrete.

The building process of drilled constructions are possible thanks to wide range of mining technologies. Their choice depends on the geological circumstances *in situ*. The diversification of geological layers may require the use of several types of mining technologies.

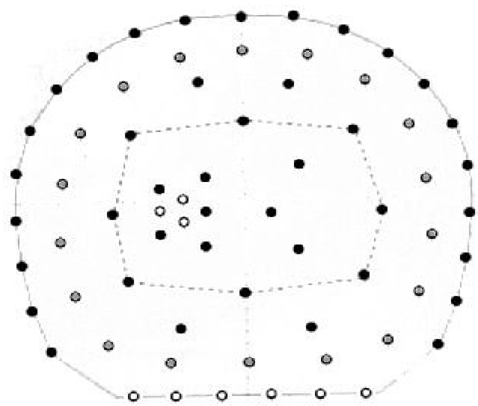
Digging would be one of the main ways to remove the surface regolith on Mars. To do this there could be used a trencher, a tracked excavator or easy hand-tools. Hand-digging is energy and time consuming, however, it is much more accurate, so it is really useful for the detail and finishing work. Tracked excavators allow the whole process to mechanize. In Martian environment using the machines would allow releasing people from exhausting and dangerous in such conditions work. Gertsch and Gertsch (1995) analyze different types of trenchers in terms of their usefulness in Martian conditions. A trencher transported to Mars should not be heavy and large. There are the small ones, internal combustion types, that would be the most effective in such harsh conditions. Depending on the range of arm of a trencher the depth of digging differs. In case of the smallest ones their range limitation is about 2 m. Machines may go deeper into the ground on a ramp they can dig, and move on with consecutive stages of their work.

Drilling seems to be the best solution for the output of medium density rock-mass on Mars, and making holes in the hard density rock-mass. Hand drills are considerable light and easy to pack tight, so their transport to Mars should be cheap. However, to have to work with them seems to be exhausting and rather dangerous. That is why they are not recommended for Martian conditions to build the base. They are substituted often with drilling machines, which require one person to operate them. Mechanization of the work contributed by drilling machines is a great challenge for modern technology. However, a machine equipped with monitors and sensors could be operated from a safe distance. The mining vehicle is a wheeled machine equipped with several drills on bending pneumatic arms (Pict. 6.31). It ican drill in a level terrain, as well as in slopes and vertical escarpments. However, it is a rather expensive machine, which transport to Mars would be also cost consuming. It would require spare parts, mostly drills. Nevertheless, once transported to Mars, it would serve to many different kinds of work, and many times.

Gertsch and Gertsch (1995) mention also TBM (Tunnel Boring Machine). They are huge integrated machines to build very long, straight tunnels, in almost any geological conditions. Transportation of such a machine to Mars would be very expensive.

To work in Martian high-density and very high-density rock-mass requires appropriate explosive technology. **Holes exploding** is now the most widely used mining technology to work in high-density rock-masses. First, there are drilled small holes in the rock, and the rock around them is blasted. The larger diameter of the out-put, and the higher density of the rock-mass, the more holes should be made, closer one to another. To maximize the effect of explosion the holes closer to the center should be larger than the ones closer to the perimeter. Many small holes on the perimeter of the designed structure ensure smoother surface of the cave and more precision of the work done. This is the so-called *contour blasting*, in other words, an outline or smooth-wall blasting (Hobler 1972, p.207). The example specification of blasting pictures is shown in the Pict. 6.32. There are two types of explosions: short and long holes. In the first case holes' length vary from several centimeters to six meters, in the second case—their length exceeds six meters. The longer the holes, the faster out-put is done, the shorter the holes—the more precise out-put is. Explosions made in long holes is the most effective: in terms of one explosion much space is created, and only several explosions may be enough to achieve a large cave. However, this method requires a machine equipped with long arms, as e.g. a heavy and energy consuming boring vehicle. The time for the dust to settle down is long, and there is much output and explosion gas to be removed from the work-place.

Picture 6.31: Drilling vehicle (Deilmann-Haniel mining systems)



Picture 6.32: The example outlay of drilling holes in the outermost of tunnel (Kuczyk 2002)

Explosions made in short holes require only small and light equipment, which can be usually used repeatedly. Some of them do not require spare parts, with their practical utility unchanged. During the mining process it is easy to adapt it to changing geological conditions (e.g. manipulating with gas pressure: higher for high-density rocks, and lower for low-density rocks; thus the work becomes more effective and energy-saving). Such a technique is less invasive to the environment: lower tension in the rock-mass, lower level of noise and safer for people—a person may stay closer to the work-place without any negative effects on one's health and life. However, short blasting holes is much more time consuming. There may be the need to make more holes, close one to another, when the equipment is not as effective as EM (Explosive Materials)

Drill holes may be made in different technology: mechanically (drills), physic-chemically (temperature, explosion, plasm, ultrasound, laser etc.) or by combination of those (Hobler 1972, p.268), (Hobler 1972, p.206). Each type of boring holes requires different type of equipment. The most effective for mechanical drilling on Mars should be rotating hammer-drills, which are recommended to work with high and very high-density rock-mass. Drilling for blasting is recommended for any types of rock-masses, and it is very effective. Plasm and laser drilling is also very effective, yet energy consuming at the same time. Researches conducted in laboratory show that microwaves are effective for even the densest types of rocks, even basalt and granite. However, they may be used only for the dry types of rock. Those waves are emitted by an apparatus called magnetron. Its advantage is a small size and weight, as well as it is a low-energy consuming equipment. Chemical boring is also very effective. The combination of chemical substances should be analyzed on the grounds of their usefulness in Martian environment.

The rock with drilled holes may be exploded in different ways, e.g. by holes shooting with explosives, cardox and airdox, static rock breaker, foam inserting breaker, plasm breaker. Only explosives are in use to blast rocks with the use of long holes.

Holes shooting with explosives is the most common and economic method of drilling holes in high and very high-density rock-mass on Earth. Many different types of explosives are used with this method[4]. The choice of explosives depends mainly on the geological and mining conditions *in situ*. To initiate the explosion there are used detonators and the electric explosion wire (there might be also a non-electric wire made from Nonel[5] pipes). To cap the explosion hole a wadding is needed. As

4 The detailed catalog of explosives and the equipment to shoot is to find in the book by Batko P., Slezak J., Lewicki J., Morawa R., 'The Shooting Technique 1.: mining explosives and shooting equipment', Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Krakow 1998

5 Nonel pipes are coated with plastic resistant to mechanical damage and high temperature. The inside of the coating is evenly coated with powdered modified secondary type of explosives. Detonation takes place inside the pipe, no matter how long it is, without any side effects like tearing up pipes (Teberia 2007).

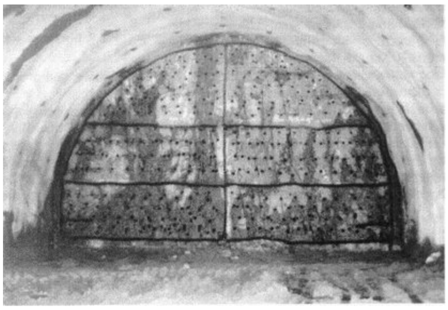
Hobler writes (1972, p.175), wadding is crucial for the explosion. It may be made from different kinds of materials. Martian dry and powdered regolith may be use successfully as dry wadding. Wadding made from powdered materials characterizes high quality and usefulness, e.g. it may be mechanically put into holes, the preparing and transportation costs stay low, and its friction modulus is high. What is more, some of the wadding is melted during explosion, creating a monolith kind of a considerably strong cork in the hole. Expanding wadding, e.g. made from a special kind of firming concrete, allows the bulk of blasted rock-mass to be considerably larger, and the explosives consumption drops even by 30-40% (Hobler 1972, p.186).

The use of electric explosion wire allows the precise delay time for the explosion to set. Usually, the delay time between the explosion of adjoining holes is very short —a fraction of a thousandth of a second. It is called then *a millisecond explosion*. As Hobler (1972, p.186) explains, millisecond explosions are used to lower the seismic impact of the blast and to increase the rock-mass crushing effect. It may increase the whole out-put of holes explosions. The blast with at least 50 ms delay release such small vibrations in the rock-mass, that there might be created two separate tunnels close to each other (Wu and others. 2004). Ruston (1998) explains that when lowering the vibration effect is the main issue taken into consideration, millisecond explosion should be performed. However, if the contour is the most important issue, it is better to blast all of the explosives in the contour explosions.

Fast and effective in the high-density rocks, e.g. granites, are explosions in the long holes (even above 8,5 m). A carefully prepared explosion specification allows achieving a mining excavation with a self-sustaining ceiling and really smooth walls. The output is created with well crushed and similar in size rocks, so they are much easier to remove. Such an effect was created while building science laboratories in Winnipeg, Canada (Kuczyk 2002). The mining excavation right after explosions is shown in the Pict. 6.33. It is clearly visible that the output is perfectly crushed into small size rocks. A cleared mining excavation is shown in the Pict. 6.34. There are only some uneven parts on the walls and ceiling visible. The mining excavation was created there with the contour explosion. That type of explosion has one great disadvantage: the dust is really thick right after explosions. To continue work it is necessary to wait for dust to settle, even for several hours (Zabuski 2006), or pump out the dust into the atmosphere. Pumping out the dust increases the work performance, however, it requires some additional energy consuming equipment, which creates an unfavorable effect on the whole while building Martian base.

Picture 6.33: The output layer after explosions in long holes (laboratories in Winnipeg) (Kuczyk 2002

Picture 6.34: The inside of a mining excavation with smooth walls, the underground laboratories in Winnipeg (Kuczyk 2002)



Picture 6.35: The view of the face of the tunnel walls after common and continual drilled holes. (Noma and Tsuchiya 2003)

Holes explosions is not limited only to the use of explosives. There are other high effective methods that might be used even in case of high and very high-density rock-masses. One of them is PCF (Penetrating Cone Fracture). It is controlled rock crushing with introducing hypertension in shallow, up to several centimeters long, holes. The crushing tension creates a cone cave after the output falls down. This method is elaborated by Singh (1998). It is one of the most effective as to energy-saving methods of breaking rocks. It is also a considerably safe method, and its use characterizes with low influence on the rock environment. PFC is really competitive to EM in case of dusting—it is considerably lower.

There are several kinds of this method with the use of different equipment. One of them is Static Rock Breaker. It is built from nickel-titanium alloy rods. It is a Shape Memory alloy. At the first stage, the rods are pressed to the minimum size. After heating they expand. It creates pressure on the surrounding rock-mass and crushes it. After cooling the SMA rods come back to their original size, with a complete recovery of their strength input. Because of that, this method is very effective and energy-saving, and the SRB does not wear out. The conducted tests prove also that it is fast—it can crush concrete and granite in 2-5 minutes.

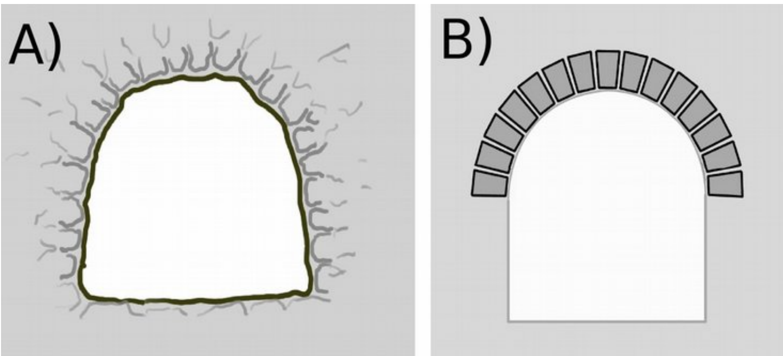
Another method of PFC is plasma blasting. It is an energy-consuming method, however, very effective in case of very high-density rocks, at the same time. Its advantage is no side effects as dust or too much output dispersion.

Rock-mass may be blasted with pressurized gas too. To do that on Earth, pressurized air is used (airdox), or carbon dioxide (cardox). Cardox method is blasting rocks with instant expanding of pressurized CO_2 from a cartridge-tube inserted into a drilled hole (Hobler 1982, p.387). Usually, liquid CO_2 is used, however, the technical improvement (by Polish scientists) made it possible to use dry ice, inserter manually, what is more effective. It is especially effective type of blasting in Martian environment where CO_2 is one of the most common gases in the atmosphere. Singh (1998) explains what the cartridge-tube is: it is a steel pipe, about 125 cm long, which may be used repeatedly, without being damaged.

Noma and Tsuchiya (2003) show an alternative method for the continually drilled holes to create smooth-wall drilled mining excavations. It ensures minimizing vibrations in the rock-mass during the process. This method was adequate enough to build two-lane excavated tunnels, where there were many houses nearby. This method consists in enlarging uncovered surface (the face of the tunnel) by making many adjacent drilled holes and simple holes, as it is shown in the Pict. 6.35. To crush the rocks then, a special type of a rock breaker is used. It is safe for the environment and effective. It may be useful to make excavations one close to another one without any additional reinforcement in the pits, what would be especially useful on Mars while building a base.

Housing of the Mining Excavations

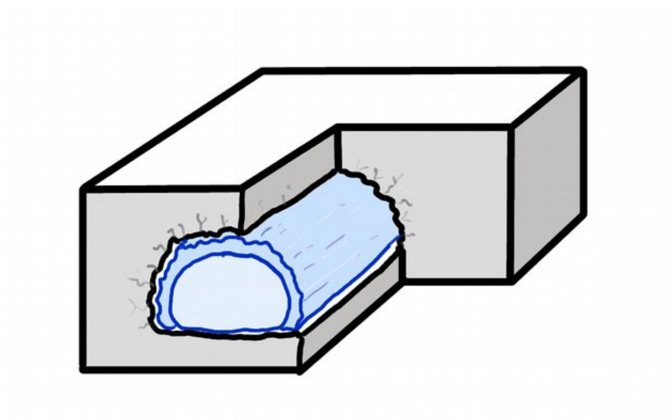
Making a hole in the rock-mass causes changes in the tensions inside the rock environment. When a piece of the rock-mass is removed, the rest of the rock-mass adapts to new conditions. Chudek (1986) writes that the rocks surrounded with mining excavations may differ in their stability: it may be a permanent stability, a tottering stability, and the rock-mas may become completely unstable. Solid and partially solid rocks, among others—basalt rocks, characterize with permanent stability. As Chudek insists (1986), mining excavations in solid rocks, resistant to pressing, preserve their stability for a long time and does not require any additional reinforcement in the rock-mass.



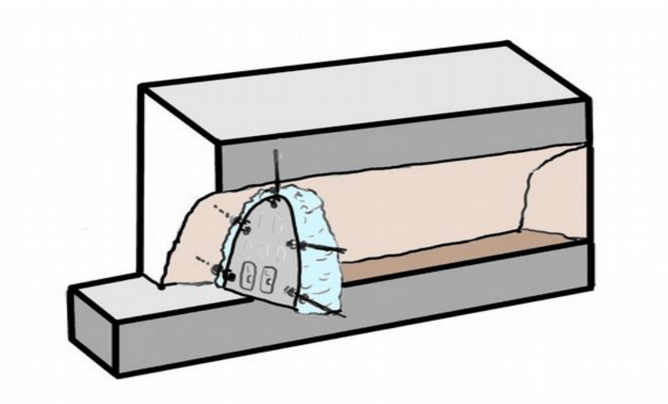
Picture 6.36: A)self-sustaining ceiling, B) quoin arch

Granted that on Mars the excavated base would be built in resistant basalt rocks, there should be possible to achieve self-sustaining ceilings, which would not require any additional reinforcement (Pict. 6.36 A). As Zabuski (2006) explains, rocks in such a mining excavation scrunch themselves up in a form of quoin arch (Pict. 6.36 B). Where the rocks are more unstable, or their lamination is unfavorable, a kind of housing is crucial. The housing consists of a support and a case. Support is the element adjacent to the rock, responsible for reinforcement of its stability. Case is usually a separate building structure inside the mining excavation, which is the aesthetic final touch for the support inside it. The support is always separated from the case with air space, Styrofoam, felt etc. (Zabuski 2006).

Building the housing means rising the cost, especially in case of a case. This would be the crucial agent on Mars for the profitability of the whole attempt. However, it should be remembered that on Earth the flexibility of a project and design of underground structures there are always taken into consideration specific conditions of the place for building. On Mars, there could be found a place for a base, where the best stability of the mining excavations is anticipated. Additionally, when choosing less rock environmentally invasive drilling type, there is a chance to eliminate a need for the housing. In case of blasting explosive materials, smooth-wall shooting ensures higher stability of the mining excavation. There is also no need for the heavy case on Mars, which is most often made form ferro-concrete on Earth.



Picture 6.37: Pneumatic reinforcement of the mining excavation



Picture 6.38: The entrance wall, obturating the mining excavation

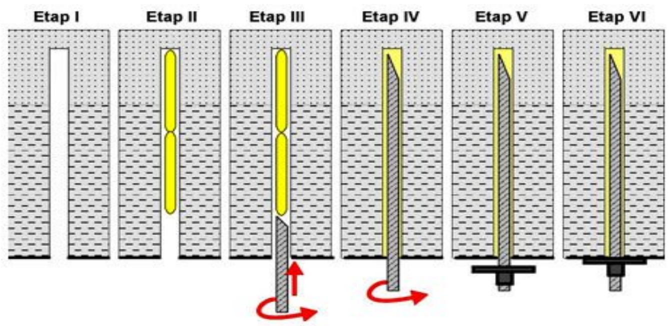
The author here specifies four methods of indemnifying of mining excavations, which could be well used on Mars on relatively low cost, and at the same time ensuring their good performance. There are elaborated four types of of housing below: pneumatic, spray-applied, anchorage, and plasm.

Pneumatic housing: Pressure of the rock-mass above the excavations may be defied with the same pressure level, created with the help of e.g. gas pressure. There could be built a kind of pneumatic pillow to reinforce the ceiling. It would be suspended above the ceiling of habitat space, as it is shown in the Pict. 6.37. It would create a pneumatic housing, with the adequate gas pressure inside the pillow to reinforce the ceiling best (the pressure inside the pillow should be slightly lower than in the habitat space). The pneumatic pillow, the air-bag, should not create too much tension on the ceiling, which would create too much expansive tension in the rock-mass. The air-bag should be made from a durable material, hard to wear off and perforate.

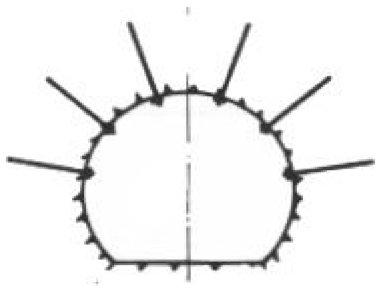
Spray-applied housing: Sprayed housing, as Chudek (1986) explains, is a housing made from sprayed concrete (torkret) applied on the uncovered surfaces of the mining excavation with a special equipment, the so-called torkret machine. Torkret is stuck to rock surface, obturating holes and crevices, merging loose rock parts, preventing them from getting loose. In the loose rock-mass it is crucial to reinforce concrete with a net or anchorage. The torkret layer covers the mining excavation, protecting it against fire and humidity. A thin layer of torkret does not create an aesthetic housing of the mining excavation, because the uneven walls are visible. However, a thicker layer of it may create smooth ceiling and hewn walls. The equipment, which should be transported to Mars to make the applied sprayed layer is: a mixer, torkret machine, ventilator of the pressurized air, and spray nozzle. Torkret is a very fast binding kind of concrete. The time it needs to dry depends on the additional circumstances. On Mars there is no water in liquid state, and the process of water evaporation from torkret could be interrupted, or—even worse—water could freeze. That is why it is suggested to seal the mining excavation to create environment adequate for the use of torkret. The sealing could be done with a cork made from an air bag filled with pressurized gas, put at the entrance of the underground passage. Alternatively, there could be build a firm wall sealed on the contour with air-bags, sprayed foam or any other type of isolator (Pict. 6.38). There could be installed windows, a door and an airlock in the ready wall, and it could be a final entrance passage to base. The wall should be additionally anchored to the rock.

Anchored housing: Anchored housing is considered as one of the most economical and at the same same time one of the most effective on Earth. The methodology of building it describe Stopyra and others (2004). it is built by anchorages inserted into the drilled holes in the ceiling and hewn walls of the mining excavation. To ensure anchorages stay firmly in their places there should be used glue cartridges (they should be probably transported from Earth). The stages of building it are shown in the Pict. 6.39. This kind of housing is economically competitive for the complicated reinforcement structures. At the same time, it is the most expensive here, among others elaborated in this work. As Huang and others (2002) explain, the anchorage housing is built in the ceiling, arch shaped. The cross-section of mining excavation should imitate a quoin arch. Anchorages stabilize the rocks by forced division and press them, exactly as it works in the quoin arch. The scheme of anchorage housing is shown in the Pict. 6.40. Anchorages are long steel screws, which should be inserted into rock with a help of special equipment. If production of the anchorages would be possible on Mars, and they would be made from the materials *in situ*, the cost of the building would fall significantly. To drill holes for anchorages there could be used drills or drilling vehicles.

Plasm housing: Melting rocks with plasm is a modern technology possible to use on Earth, to stabilize weak grounds for building structures, bridges, roads etc. Mayne and Beaver (2002) describe how to put this method into practice. A plasm torch is installed on the bottom of a prepared hole. The turned on torch heats gas into plasm, which melts surrounding rocks with its high temperature. There could be used any mix of gases. This way a mining excavation could be stabilize on Mars (instead of steel anchorages). The best would be to treat the whole surface of excavation with plasm. Recast basalt is incredibly strong and resistant to pulverizing. The surface of basalt rock glued with help of the plasm torch would be really durable. The plasm torch was designed to reinforce very weak rocks, mostly loose, such as sand (Mayne and Beaver 2002). Its appropriability to reinforce rocks in the underground base on Mars should be analyzed further. The most important obstacle for using it on Mars is its high level of energy consumption.



Picture 6.39: Stages of installing anchorages to reinforce the mining excavation (Stopyra i in., 2004)



Picture 6.40: A cross-section of the mining excavation with the anchorage housing

Conclusions for architect

The analysis of mining technologies based on their usefulness to build a base on Mars shows as follows:

1. Cross-sections of mining excavations may be different. Their profile is dictated by the geological and mining conditions, and their specific function. There are suggested streamlined shapes, which ensure more even dispersion of the pressure of artificial atmosphere inside. Ovoid hewn walls and ceilings ensure more stability of the uncovered rock-mass.

2. The choice of a mining technique to build the underground base on Mars influences the method of architectural designing and planning. Blasting short holes is more flexible. It gives the freedom of creating habitat's space. There are allowed curved and circular lines that way, and almost any shape of passages and caves is allowed then. Building additions and recesses would not be problematic. As blasting short holes does not create high tension in the rock-mass, and it is less invasive for the rock environment, building adjacent tunnels should be considerably easy. It is possible to plan many small adjacent holes serving as windows, doors, ventilation shafts. Blasting long holes is not the same effective to build the habitat. This method could be introduced to fast building of the several meters long (even longer than 8 m) corridors and caves. They are of the same width with the use of this methodology. However, it is impossible to build recesses then. It is possible to build adjacent parallel mining excavations. Blasting long holes is especially effective while drilling

holes of a wide range. It is easier to make larger holes to introduce light into the cave, however, not as many of them, as in case of the first methodology elaborated above.

3. There could be distinguished several mining technologies of blasting holes, which are possible to introduce on Mars to build the base: blasting EM, kardoks methodology, PCF methodology (Static Rock Breaker, plasm explosion). The kardoks methodology should be emphasized here, as it would be most effective in Martian environment. CO_2 acquired form local resources (best in state of dry ice) could be used to effective and cheap rock blasting.
4. Most of the required equipment to blasting holes may be used repeatedly. Machines and vehicles once transported to Mars, could be used for building the first base on Mars, building additions later, building next bases, and to excavate resources from geological layers. It would create the independence of such a base from transporting supplies from Earth, and assure its unlimited spatial development.
5. A place to build Martian base should be chosen regarding the best geological conditions to eliminate a need to build the housing of the mining excavation. Such a housing significantly rises a cost of building of the underground base. Still, if the housing would be necessary, there should be found the most economical solution. There are available, among others: pneumatic housing, anchorage and plasm.
6. Application of mining technologies to build underground Martian base seems really promising. Gertsch and Gertsch (1997) conducted the preliminary tests which resulted in positive prognosis. There are still, however, many problems waiting to be solved. The author here gives some of them:
   (a) There should be chosen suitable drills in case of mechanical drilling. Currently there are conducted works to design the best possible drill to micro-drilling for the needs of unmanned missions to Mars (Harpole 2006, Schrope 2000, Blacic and others 2000). The technology of their production was identified and after some tests *in situ* there will be possible to improve them in regards to planned base.
   (b) It is crucial to assess a level of energy consumption of each of the method preliminary accepted to be adapted on Mars. For example, a use of blasting EM produced form local sources seems promising in regard to lowering the costs level. However, the local production may be very difficult and dangerous, and acquiring local sources would need some heavy machinery.
   (c) In the dissertation here, the problem of removal of the output and its transportation is treated especially carefully. Gertsch i Gertsch (1995) suggest the use of proper vehicles in their publication. It would be really of some value to specify alternative to the Earth's transportation technology with the use of lighter vehicles. On Mars everything is lighter thanks to lower gravitation, and thus backhoes could be disproportionately bigger than it is required on Earth. The construction of excavators alone would be

designed to minimize its weight. Ballasting to stabilize it would be done locally with putting some regolith into a tank planned for this.

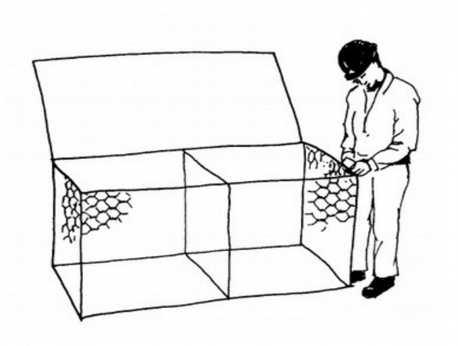
(d) Explosive materials should be chosen in regard to their usefulness in Martian conditions. First of all, they should be resistant to extremely low temperatures, and to the whole variety and concentration of gases in Martian atmosphere. They should contain an inflammatory factor, as oxygen. The wiring that needs oxygen in the atmosphere cannot be used on Mars, thus the most probable would be the use of wiring net: electric or non-electric (Nonel pipes). It is profitable to make EM *in situ*. It is crucial to check carefully local resources to find the best and the easiest to achieve sources to make EM. The less sources should be supplied from Earth, the best, in regard to the safety standards and costs. It is also very important to underline here that many EM has a very short expiration date, or their transportation is really dangerous.

6.1.4 Regolith and stone construction

To build a regolith and stone construction there could be used: stone blocks, stones and earth. Stone blocks may be cut out from large-surface stone blocks or from uncovered from under the surface stone blocks[6]. Stones could be gathered straightforwardly from the ground or from the removed excavated output. The earth could be collected with shovels, excavators or drawing in equipment. All of the building materials are easy to obtain, practically without limitations, on the whole planet. That is why any technologies based on such building materials would be sufficient in any localization there, what significantly lowers the overall costs. At the same time, there would be no need to supply building materials from Earth in case of reparations or for building additional habitats. It should be enough to transport the equipment from the first base to the next localization.

Earth and stone buildings have been constructed by people for ages. There are devised many different techniques enabling such types of building. The author here specifies the most promising ones, which could be applied on Mars. As for building materials, there could be useful: gabions, stone blocks, earth and resin blocks, bricks, pressed earth blocks, Superadobe and multi-chamber bags filled with earth.

6 Onderka (1992, p.113) describes the methodology of separating the stone blocks from the rock-mass with the help of EM.



Picture 6.41: Worker installing a gabion (BMTG)

Picture 6.42: Excavator loading gabions (BMTG)

Gabions: Baskets are boxes filled with stones. Cuboid baskets are made from specifically interlinked wires are gabions (Pict. 6.41). They are lasting and difficult to damage, if made from good stainless steel. Their duration level increases in time, when sediment settles between the stones (Jarominiak 2000). Baskets are transported to the spot in bunches. That way they occupy little place, so their transportation is cheap and easy. Their installation on the spot consists in assembling a basket from flat elements and connecting them by their corners. The connections may be done by hand, it is trussing up with wire, or with the help of steel clips installed with a stapler. Additionally, there could be installed firming diaphragms. The assembling and loading the basket is rather easily done, it is why there is no need for workers to be experts. Gabions are filled with rock material, slightly larger than meshes. It may be filled also with geotextile fabrics and completed with regolith. Filling in the baskets is usually done by diggers (Pict. 6.42). A basket made from wire keeps in the shape of gabion, but at the same time it is not as firm as not to undergo slight deformations, applying itself to the shape of the ground. The material for filling in the baskets is most often taken from local sources. Gabion constructions do not need expensive supporting and are easy to repair. The maximal height of constructions built that way on Earth is up to 8 m. Gabions may be useful to build reinforcing walls, construction walls, division walls and fences. However, they are not useful to build ceilings.

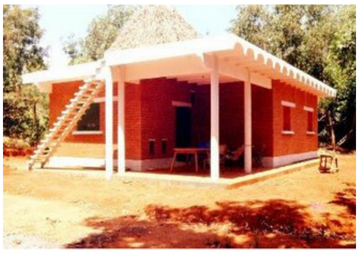
Stone blocks: Stone may be used to lay constructions in different shapes. The better is stone processed, the easier to build a regular low wall of it, and the less usage of binding material. However, at the same there should be larger amount of work put into preparing the building material. To process stone, a sew with diamond discs is used, such as BMTG (www.bmtg.eu) offers. The producer suggest manipulation of the disc speed applying it to different kinds of materials to make it suitable for cut stones *in situ*. Diamond discs may cut across any material, even hard basalts They could be additionally polished to lower to minimum the quantity of binding material. With the use of such an equipment there could be made high quality blocks. However, even not so even stone blocks would be enough to build a base, accordingly with more quantity of binding material, and the time to fit stones would be much longer.

Resin and earth blocks: The regolith doused with the specific binding material is a good material to form blocks to build the walls of habitat. Loose Martian earth could be bonded with resin. Kim and others (1998) conducted analyses of different resins and chose ICI Fiberite 934 as possible to be recommended for Mars, because large quantity of light elements in there, its radiation absorbing ability rises. It is a substance well known in the aerospace.

Bricks: The bricks production on Earth usually consists in making clay mass from specific components. The mass is cut into blocks of a designed shape, next they are dried and baked in specific kinds of ovens. On Mars such a production would require transporting the whole manufacture from Earth to perform all those actions. MacKenzie (1989) suggests to use the local regolith to produce bricks. There is a chance that from local resources there could be obtained also additional components to improve the quality of bricks, e.g. lime. Bricks production would be energy consuming due to the need of heating ovens to high temperatures. The higher the temperature is, the better bricks quality is, but the higher production costs at the same time. As MacKenzie (1989) persuades, however, satisfactory quality of bricks is achieved at the temperature of 300°C, especially when there is added binding material. He continuous that on Mars there should be no problems with heating ovens up to the temperature of 900°C (this is the temperature contemporary used to production of bricks of the best quality), using a sun-mirrors furnace or waste heat from the nuclear reactor of the base. He points out that the production process requires water, but in the properly built oven almost all the required water would be recuperated from water vapor created in the process of drying bricks, in the temperature of 200°C, before the baking process starts. He insists also that after mixing dust slit collected from surface, a good binding material is possible to obtain to bind bricks.

Picture 6.43: A machine to product earth blocks (AECT)

Picture 6.44: A cutting machine to make earth blocks (AECT)



Picture 6.45: A house built from CEBs (E. Hunting)

Picture 6.46: Interiors of the house built from CEBs (E. Hunting)

Blocks made from compressed earth (CEB): On Earth, in warm countries, mostly in dry climate, there are used in building constructions blocks made from compressed ground (CEB—compressed earth blocks). Production of such building material is surprisingly easy, and the required equipment—easy to operate, and relatively easy, so it would be transported to Mars without any problems, and operated by Mars mission staff. The machine to compress blocks is shown in the Pict. 6.43, a cutter to cut the blocks into required size—in the Pict. 6.44. Compressed earth blocks are easy to form and obtain in any planned shapes, what makes it possible to plan more sophisticated architectonic forms. In the Pict. 6.45 and 6.46[7] there is shown a house built in this technology. However, CEBs may be made from specified types of earth, usually good absorbent (Delgado i Guerrero 2007). The slit Martian ground responds to those criteria, however it should be first well moistened. The advantage of those blocks is their low build-in energy and easiness of their production[8]. On Earth the main problem with those blocks is their low water resistance—rain can easily ruin this material. CEBs carry a little lower loading than baked bricks, and are good to build low buildings. Compressed earth blocks are not durable, but it is easy to improve their properties. As Ngowi (1997) writes, the most effective earth modification to produce earth blocks is: tamping it or adding components (the best are lime or cement). Even in the ancient times a reinforcement method was discovered: mixing the mass with straw. That way there was produced one of the first composites in the history of man. The base builders could add to bricks some inedible biomass e.g. in the form of fibers from stems, or just straw. The source of those materials would be obtained as waste from plants grown in the artificial ecosystems. Thus, as MacKenzie (1989) suggests, pieces of fabric from parachutes, which would be used for stopping the landing transporters, would be an ideal additional composite.

Laying in stone is connected with the use of moist binding material. Such binding material is crucial on Mars: it connects blocks into a monolith wall, reinforcing its durability, and closes crevices between bricks, which could let out gases from the atmosphere inside the habitat. It would be a challenge to produce such a binding material, which would keep its properties for a time long enough. Stone blocks may be bonded with fast drying resin sprayed into the crevices. It should be resistant to low temperatures not to crumble. The resin should be transported from Earth. To use a traditional binding material in the form of ground of resin, the work should be performed in hermetic environment. The building site should be covered and air-tight. The insides should be filled with artificial atmosphere. Conditions should be prepared properly for evaporation of water. Ngowi (1997) explains that water evaporating too fast causes usually crevices, and too slow—slows down the building process. The covering could be temporary or permanent—as an element of the base. In the first case there could be used less resistant material than in the second case. If the covering were to become a permanent element to keep the base air-tight, the brick building could be shaped more like they are on Earth, they could be pargeted and painted.

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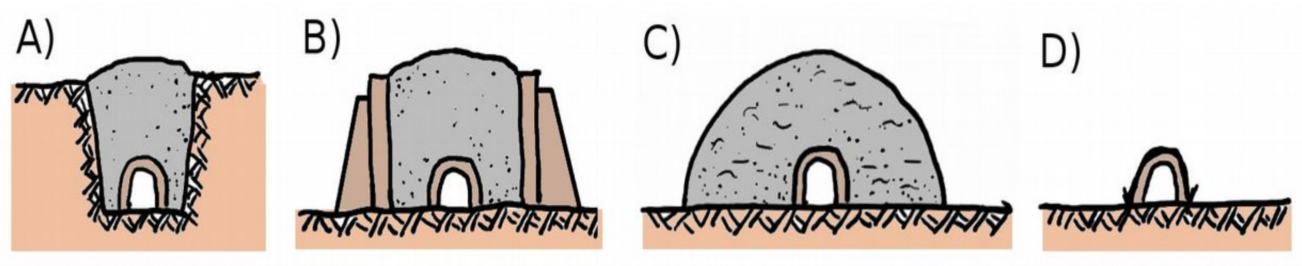
7 The pictures come from Hunting E. „The Myth and Promise of Dirt Cheap Housing", http://radio.weblogs.com, 2003

8 It is highly suggested by the company which specializes in the technology of building houses from compressed earth blocks, AECT – The Advanced Earthen Construction Technologies, Inc., http://pages.sbcglobal.net/fwehman/index.html



Picture 6.47: Different types of pressing layed with stone construction (described in the text)

Instead of using binding materials, the blocks could be connected in a different way. They could be shaped in such a shape that it would be easy to connect them without any additional help, e.g. Dovetail Joint. However, to shape bricks in such shapes would require them to be of a very high quality, what could be very demanding in Martian conditions, but still possible. Stone blocks, on the other hand, could be cut with precision to obtain demanded shapes. Additionally, they could be polished to gain such smooth surface as to keep them tight one to another in a construction.

Stone blocks, as the author thinks, may be welded, melted in places of connection with a heating equipment, e.g. laser or plasm torch. Basalt blocks would require much heat. Less energy consuming method would be as such: between the blocks there would be put some sand, and it would be the sand to be melted, not basalt blocks, to join the blocks. This solution, however, requires equipment to create high temperatures. However, there is no need to use any additional binding material. Sand would be collected *in situ* from a surface of the regolith.

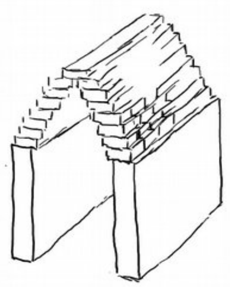
Stone-masonry is resistant to pressing, but not very much resistant to stretching. That is why, as MacKenzie (1989) explains, they should be pressed from the inside on Mars. Only then they would be able to counteract stretching, which accompanies hypertension in the base. MacKenzie (1989) suggests such constructions to be ballasted with a layer of Martian regolith. As Petrov (2004) writes, the inside atmospheric pressure similar to the one in Skylab (about 1/3 of the Earth's atmospheric pressure) required a layer of eleven meters of ground. It is a considerably thick layer, and a higher pressure inside would require the layer to be even thicker. Keeping the layer in its place is possible with different solutions. As MacKenzie (1989) suggests, first a deep hole should be dug and building work would be conducted in it, and at the end it would be covered again (a so-called method cut and cover (Gertsch and Gertsch 1995)). To do that, a localization for the base should be found in a place where regolith should be considerably loose and reaching deep enough into the ground (Pict. 6.47 A). In any other case, some specific technologies should be applied to drill a hole deep enough in a hard rock. There could be also built high buttress walls and the habitat would be built between them (Pict. 6.47 B).

To eliminate the need of building specific types of walls there could be used *texsol* instead. As Jarominiak (2000) describes, it is a mixture of sand and continual polymer thread, achieved by blowing or throwing out those components on the reinforcing surface. Sand and tangled thread create dense enough material which characterizes with a good durability. The speed of applying those components is crucial here to disperse them evenly. As Jaromniak (2000) follows, texsol is resistant to e.g. wind erosion. It is a kind of composite, because it behaves as one. Its resistance is enough to achieve almost vertical surface (60-70°), and almost 10 m high, with a large safety rate. Making texsol requires machines throwing out its components, which should be transported to Mars from Earth. It is possible that a thread could be produced on Mars.

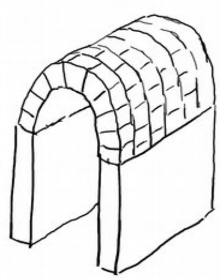
A thick layer of the ground does not only ballast the tense stone-masonry structure, but also protects it against the Sun and Space radiation. However, providing some heavy equipment from Earth is crucial for the method to dig in the ground, covering the base with the regolith etc. An alternative is tightening a layed with stone construction with a net or fabric made from e.g. Kevlar fiber anchored firmly in the ground (Pict. 6.47 D). One of advantages of this solution is the look of such construction, and it is easier to install windows in it.

As the insides of base should be filled with artificial atmosphere which pressure should be higher than it is on Mars, the base should be streamlined in shape. In case of a stone-masonry, it is possible to achieve such a shape by building arches.

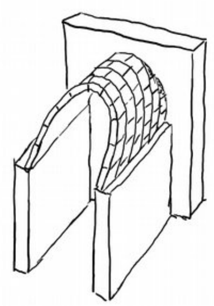
Corbel arch: The earliest ceilings built on Earth is corbel arch ceiling (Pict. 6.48). It is an arch-like construction method where consecutive layers of blocks are put on the opposite walls to the moment they meet at the top. That kind of arch was used most often to cover circular or rectangular rooms. Cone domes of that type are known from Aleppo (Syria), Apulia (Italy) (Basista 1995, p.39). Their advantage is that they are very easy to build. Ceramic and stone blocks are enough to build a corbel arch. However, a cross-section of the ceiling is triangle, not rounded, and its profile is more stair-like, not even. Such a covering is not recommended to even dispersion of atmospheric pressure inside the base.



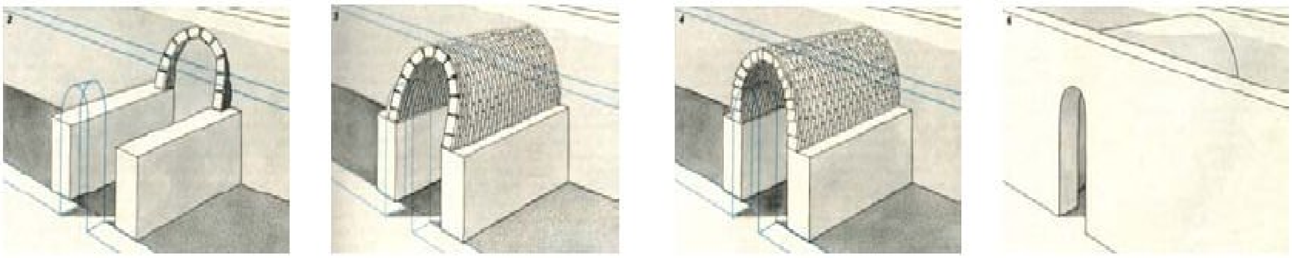
Picture 6.48: Corbel arch



Picture 6.49: Barrel arch



Picture 6.50: Slanting barrel arch



Picture 6.51: The stages of building slanted barrel arch (Petrov 2004)

Picture 6.52: Working out of proportional dome with a help of the stick (Petrov 2004)

Picture 6.53: Building the dome without a truss (Petrov 2004)

Picture 6.54: An inside of the dome with windows (Petrov 2004)

Barrel ceiling: The origins of first barrel ceilings come from ancient times (Pict. 6.49). Their construction is created by stones layered on vertical reinforcing walls. Such a ceiling is a very durable one because of the pressures inside it, which causes the stones to press on each other, thanks to gravitation. A binding material is not necessary. However, the right construction requires a truss to build it. Elements of such a truss should be prepared in advance on Earth and transported to Mars. Its assembly should be easy and not taking much time. The weight of the truss should be as low as possible, to minimize costs of transportation. As the author here points out, moving such a truss around should be easy then, if it was not very long, and putting it for the next part of construction should be effective in a short time. Sometimes, to build such arches on Earth, there are used temporary pneumatic structures (Tarczewski 1965). They could be a good solution for Mars to build domes, as well as barrel arches. One expandable construction in a shape of hemisphere, and one in a shape of cylinder would be required. Such helpful expandable structures are easy to assemble and easy to move, and for the transportation they could be tightly packed, occupying little space.

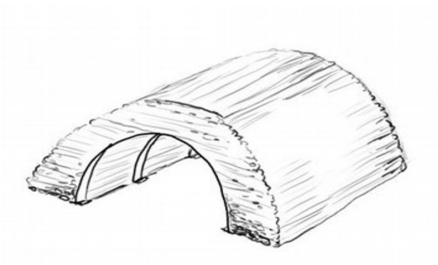
Slanted barrel arch: Slanted barrel arch (Pict. 6.50) is build on supporting each other consecutive slanted brick arches. They are regular bricks. They should be bonded with a binding material. The angle of slanting arches is of a small value, but this is enough to keep bricks from going down the slope. This technique is described by Petrov (2004). The stages of making the ceiling are shown in the Pict. 6.51. Because every arch is supported by the previous one, there is no need to build trusses. AS Petrov continues, a dome could be build in the similar technique. In such case there is no need for buttress wall—four poles connected with arcades are enough. To work out a regular dome, a stick and a piece of rope are enough (the length of rope should be measured and specified in advance, it should be a radius of a section of the dome) (Pict. 6.52). Consecutive narrowing circles support each other. There is left an opening at the top, which might be covered with a trapdoor, or left open to let the light inside (Pict. 6.53). In such a dome there might be also left openings to install small windows, as it is shown in the Pict. 6.54.

Picture 6.55: Super Adobe construction during building (Cal-Earth)

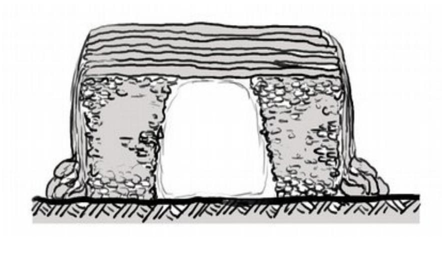
Picture 6.56: Super Adobe ready building (Cal-Earth)

Superadobe: One of Low-Tech technologies is suggested to adapt on Mars: Superadobe, invented by Nader Khalili (1999). There are used long bags filled with earth or sand mixed with cement or lime. The bags are put in layers (Pict. 6.55) and shuffled with barbed wire, which function as a cheap reinforcement rod. The bags may be made from fabric made for the purpose Adobe fabric tubing (worked out by Cal-Earth), burlap, polypropylene, or other similar fabrics (Wikipedia 2007). The foundation is build from 2-3 layers of it put under the ground-level. Building Superadobe construction is easy and there are no specific requirements as about the workers' qualifications (Aga Khan Development Network 2004).This type of construction is strong and durable; it can resist even strong earth-quakes. Khalili suggests dome-like buildings (Pict. 6.56), however, flexible construction elements may create even more sophisticated dimensional structures. It is required than to analyze how to build ceilings. The bags are filled with previously prepared mixture and put one on another, creating smaller and smaller circles, until there is a small opening at the top. It is also easy to build windows in such walls. Such a construction does not require any specific, expensive materials, and the water and cement quantity used in the method is minimal (Husain 2000). Superadobe buildings are airtight, even though they do not require any binding materials. They are more resistant to tearing than stone-masonry. One disadvantage of this technology is the need of using liquid water.

MacKenzie (1989) writes, that the researches conducted in Martin Marietta's laboratories prove, that Martian ground is sufficient to make from it a material called *durikret*, which imitates cement. This material could be used in Superadobe constructions. An engineer, Robert Boyd, says that durikret may be obtained by a very easy process, which requires only moistening and drying Martian earth. This material is 50% more resistant than cement widely used on Earth. MacKenzie assures also that there is a chance to achieve lime from local resources on Mars, thanks to which there could be produced a standard Portland cement of high duration (Zubrin and Wagner 1997, p.237).



Picture 6.57: Construction made from multi-chamber bags supported on arches.



Picture 6.58: Ballasted construction made from multi-chamber bags with a ceiling.

Picture 6.59: Multi-chamber bags with firming supporters: up—unfolded, down—folded.

Multi-chamber bags with earth: All the above elaborated technologies require water in liquid state to perform, in variable quantities. It is insufficient in Martian environment. The author here suggests to obtain dry Martian earth to build habitats' constructions. There would be required previously shaped into specific form multi-chamber bags, later filled with earth. Put in layers, they would create a strong and stable construction (Pict. 6.57). To build ceiling there would be needed supporting arches, e.g. made from steel, shaped into required form. Those arches (ribs) would be transported folded, from Earth. An alternative to this would be putting multi-chamber bags as crosswise coverings with ballasting at the end (6.58). The author suggests here that the bags should consist of several connected tubes. Filling could be done mechanically. A machine to do that would not be large, and it would work as a kind of vacuum cleaner. It would suck the earth from the ground and pump it into the bags. To speed up the whole process the machine could be equipped with many pipes to attach all of the tubes of one bag at the same time. The firming supporters in bags could be made from rigid reinforcement in each tube, as it is shown in the Pict. 6.59. Those supporters would be added only in specific parts of the bags, that is why during the transportation the bags would be flat, and only after unfolding and filling up they would create a dimensional form. There could be used flat bars made from metal or light plastic. Sufficiently flexible plastic in parallel lines, and put crosswise firm plastic supporters would allow creating even walls, e.g. with curves etc. The smaller chambers, the smaller subsidence level of the construction, but the larger amount of bags.

Conclusions for architect

1. From Martian regolith and stones available on the whole planet in large quantities there might be produced many different kinds of building materials, as it was shown in the chapter above. One of them, or many, may be chosen to use. Variable building materials may influence positively the outlook of the base. To limit the quantity of required equipment there might be delivered multifunction machines to use for the whole variety of tasks, e.g. an excavator may be used to collect loose Martian regolith to bricks' production, and load stones to gabions.
2. As ceilings between the floors there seem appropriable Klein ceilings or long stone plates. Klein ceilings, however, require reinforcing rods, which should be delivered from Earth, or should be produced from local resources. Large stone blocks could be cut with a special kind of saw to the shape fitting their purpose, for ceilings. Their moving and fitting in places should be easier than on Earth, because they should be three times lighter on Mars.
3. The most important disadvantage of constructions from Martian regolith and stones is their low resistance to stretching, and the elements are usually short. The consequence of it is the need to build ceilings in a special way. Ceilings and domes seems to be here the best solution. Additionally, their shape is positive for the dispersion of atmospheric pressure inside the habitat.
4. There are used contemporary reinforced constructions made from concrete, steel or glued wood to cover large buildings. However, even brick constructions can be used for the same purpose, without any additional reinforcement. As Petrov (2004) gives, the largest brick ceiling span is 25.5m[9].
5. There might be designed buildings of variable colors thanks to the use of local rock resources, what would improve their aesthetics. Brick is a very promising building material in that case because it can be colored differently. A wide range of colors in ceramic materials is possible because of different additions and the baking time. Basalt is the most common rock on Mars, but even this rock can have different coloration, which gives some possibilities when choosing colors for a habitat made from stones.
6. The use of ground and stones to build began in ancient times. Thus, there are many architectonic sources of inspirations.
7. Most of the technologies elaborated above use small building elements to build larger constructions. That is why those elements may differ in shape, what would be an improving addition to range of architectonic solutions to chose from. There could be brick division walls, studs in many different

9 It is to find in an ancient city Ctesiphon (now Iraqi). It was built between 3rd and 4th century AD.

shapes, balustrades, footbridges, entresols on ceilings or domes, introduced perforations where required. Superadobe and multi-chamber bags with earth may be use to build buildings on circular profile, wavy walls etc. The use of those methodologies helps not only to design stable constructions, but with interesting interiors as well.

6.1.5 Ice constructions

Ice on Earth is not a typical building material, because the usual temperatures in inhabitable places are mostly too high and ice melts. On Mars, on the contrary, there are sources of water and dry ice, which do not melt for the whole year round (especially on the North Pole and shaded ground depressions). In places where temperatures stay always below zero it is possible to build habitats, or parts of them, from ice. In other places those elements would not stay intact and should be protected against sublimation.

Picture 6.60: Igloo

Picture 6.61: Carved out construction in a block of snow

Picture 6.62: Ice Hotel in Quebec, outside view (IceHotel 2007)

When water freezes slowly, it creates monolith transparent elements, when it freezes fast—it creates tiny snow flakes. Ice blocks are transparent and tight, but can easily crack under high tension. That is why they are better to be cut into small blocks to create wall panels. They should not be used to build an outside reinforcement construction that should be resistant to artificial atmosphere of the habitat. Walls built from such ice-blocks would create an excellent barrier against the Sun and Space radiation. Their transparency would allow light inside to enhance comfort of the habitants. Ice-blocks could be used to build shielding walls or installed as windows in the base. Igloo has been for ages a traditional ice construction on Earth (Pict. 6.60). Ice blocks are put on the spiral, a little slanted, shape, to create a kind of dome. Snow differs in its structure from snow. Snow is created of tiny pieces of frozen water, which can stay loose or may be pressed into dense, hard elements. Snow is easier and faster to obtain than ice. Dense compressed snow may become a monolith block of considerably high mechanical resistance. There might be carved out tunnels and habitable chambers in such compressed snow (Pict. 6.61). Igloo is a considerably strong construction. It can resist even strong winds because of its streamlined shape. Its walls are good insulators and keep safe from winds. On Mars, such a construction could be built in a ready block snow, or prepared snow slope. Snow is easy to operate with, so carving out is considerably easy in it. There is no need for heavy equipment to move out snow. Any damages in the construction are easy to repair with some amount of additional material. The walls could be shaped easily into any required useful forms inside, during the building process. There may be prepared then protrusions and dimples: dens, shelves, tables, seats. Snow is also a good radiation barrier, however, it is not as transparent as ice.

It should be mentioned here too that ice as a building material may have great influence on the aesthetics of the base. Easy to shape, ice may be curved in any possible way. Ice elements could be in different shapes, and habitants could change it according to their wish. There are several examples of its usage to create different habitable constructions: Quebec, Canada (Pict. 6.62, 6.63) and in Jukkasjarvi, Sweden (Pict. 6.64).

Picture 6.63: Ice Hotel in Quebec, interiors (IceHotel 2007)

Picture 6.64: Ice Hotel in Jukkasjarvi, a corridor (Gadomska 1999)

Conclusions for architect

Ice is a very interesting building material, not very often used on Earth. There are created two main ice constructions: igloo and carved out constructions. Both of them could be useful on Mars. Ice constructions are not resistant to stretching, that is why they are good materials for outside covers against radiation and mechanical damages, or they should be pressed to the ground in the same way that layed with stone constructions should be.

1. Ice is a very promising building material. Easy to shape, ice may create incredible decoration elements. It is easy to obtain a whole range of different forms from ice, cut into blocks, and to curve and chisel it. Ice blocks may be chiseled, colored, painted easily. There could be achieved wonderful light effects form it, when a base is lit at night (Pict. 6.62).
2. Ice constructions are built fast and easy.
3. In places, where temperatures stay below zero, snow may be used as a construction material. Where temperatures are higher, it must be isolated. Ice constructions should be protected against melting from the inside, if they have contact with warm atmosphere in the insides.
4. Ice blocks are transparent enough to make windows from them, skylights, or covers which would let the sunlight inside.
5. Windows' and transparent walls' covers could perform several functions: letting the sunlight inside, guarding against the Sun and Space radiation, and against mechanical damages.

6.1.6 Isolation materials

Extreme conditions on Mars require looking for different types of barrier materials, which would keep the construction and habitants safe from different harmful factors: harmful radiation, thin atmosphere, low pressure, low temperatures and their fluctuations.

Anti-radiation isolation

ASEB (2002) informs that a long term stay on Mars causes people to receive a huge dose of the Sun and Space radiation. To minimize the effect of this radiation, which is going to influence Marsonauts, they have to be protected. Martian base should be equipped with an outside anti-radiation isolation. It may be made from different materials. The general rule is that material built of light elements becomes a better isolator. Thus, the best kind of such isolation should be made from hydrogen. However, hydrogen alone would be most dangerous, because it reacts easily with other elements, and its explosion seems a real danger here. The safest, and at the same time, the easiest to obtain, seems water—H_2O (Hoffman i Kaplan 1997). Known to us water is a liquid, and it would be use in this state by habitants, to drink it and to wash with it. Water is widely used liquid in households and work places. There should be huge amounts of it in a Martian habitat, too. It is suggested that water tanks would surround the base (Mars or Bust 2003). The larger the external surface of habitat, the more water should be required. There are large sources of water on Mars, so it should be obtained without too much effort. However, the required quantity of it would become a problem, because it is not as easy to obtain on Mars as it is on Earth. In case of a large habitat, water covers should probably be supported with other anti-radiation materials. Water tanks could be built from flat elements delivered from Earth and connected *in situ*. A firm tank could shape the water tank, and a rubber or plastic bag could obturate it. Tanks could be designed to influence the aesthetics of habitat. The temperatures on Mars usually stay below zero, ice could be used as an anti-radiation cover too. A thick layer of snow, or construction made form ice blocks could create an outside cover of the habitat. Liquid water tanks, as well as ice covers, could create transparent divisions. It would be enough to achieve such effect with making water tanks from transparent elements (glass, plastic[10]), or with transparent ice blocks. They should be recommended to use in every possible place, which should be left transparent. Finally, the whole habitat could be build from ice. Due to the protective properties, water is worth considering as anti-radiation material, at least to build a protective shelter for the time of explosions on the Sun.

Another anti-radiation material, which could be obtained on Mars, is Martian regolith. Its characteristic as a barrier is not as good as water's is, still, it is worth considering due to its many advantages. Martian regolith is created mostly from light elements (Kim and others 1998). That is why it is considered as a good Sun and Space radiation isolator. Adding some substances rich in hydrogen, as resin ICI Fiberite 934, should enhance satisfactory its anti-radiation valors. There are several methods to use Martian regolith like this. Firstly, a habitat could be excavated in a rock-mass, or established in an existing underground tunnel. That way an anti-radiation barrier should be obtained at once. Constructions built on the surface could be protected with imposed ground (Gertsch and Gertsch 1995), or ground packed into handy bags. Some kind of a radiation barrier could be created by stone-masonry and Superadobe. They are, however, too thin, that is why they would not create sufficient radiation protection.

Contemporary suggested material for such barriers for Space habitats is *demron*. It is a thin fabric (0.38 mm) which is used on Earth to make radiation protective fabric for clothes and covers. It is very flexible and light (radshield.com). It has the lowest permeability in comparison to any other material used for the purpose nowadays. However, demron is also very expensive. If not to cover the whole habitat, it would be suggested to cover windows and greenhouses at least, as the author here thinks. During the day, when rooms would be occupied and the sunlight would be required there, the cover could be left aside. They would be in use when a room would be emptied during a day, at night, and mainly during Sun-storms. That way the dose of radiation pollution reaching people through windows and other transparent surfaces would be lowered satisfactory.

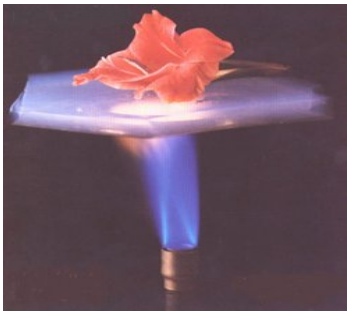
10 Glass could made on Mars from local sources (Zubrin i Wagner 1997, p.249).

A good barrier against alpha elements and protons, the main component of Sun radiation, are artificial materials made from atoms of light elements. In the TransHab project there were suggested for such purposes polyethylene foils.

Insulation

Until now, the question of insulation and thermal isolation of Martian habitats is not experimentally tested. It is supposed that such protection might not be required. Such suggestions are based on the knowledge of the thinness of Martian atmosphere, and consequently—the loss of heat from the habitat's outside walls would stay on the minimum level. Additionally, most of the equipment on the base create heat as a side-effect, when they are turned on. Because of it, in the plans of metal habitat modules for Martian base for Mars *Design Reference Mission* NASA the problem of thermal isolation is not included. On the contrary—it is pointed out that there is possible to occur another problem: how to dispose of the surplus of the heat created by people and equipment (Mars or Bust 2003).

Habitat modules for manned missions, which have been designed until now. are very small. In tight space, occupied by many different laboratory utensils and Life Supporting System, heat may accumulate inside, instead of escaping to the very thin atmosphere outside the module. Base, however, is a structure much more complicated and larger: there are planned rooms for different purposes, and equipped differently; some of them are going to be occupied more often by people, others—less. There should be constant, and more or less homogeneous temperature in the whole habitat. Otherwise, people would feel physical discomfort while moving around the habitat. Modules designed e.g. by NASA for the first Marsonauts are stabilized on metal legs. That way they are going to be separated from Martian ground. A larger habitat should rather be put on the ground, which is very cold, and so heat would escape mostly through floors. If the base should be put into the ground as a whole, the heat would escape through the whole surface of the construction, and very fast. That is why, the author thinks, Martian base requires a kind of insulation which would keep heat inside. In Space constructions—orbital and the Moon—there were usually used aluminum Sun-light radiators to stabilize temperature inside and to keep them safe from overheating. This should rather not be required on Mars, because only half of the Sun-light reaches the Red Planet in comparison to the amount that reaches Earth.



Picture 6.65: Aerogel is a very good thermal isolator (JPL/NASA)

Picture 6.66: Aerogel is very resistant to pressing (JPL/NASA)

Picture 6.67: Nanogel: kinds of pellets (www.nanogel.com)

Picture 6.68: Aerogel fabric, Cryogel (Aspen Systems Inc.)

Picture 6.69: Microtherm, quilted panel (Microtherm)

Picture 6.70: Nanopore Panels VIP (Nanopore)

Modern technologies make it possible to use a whole variety of insulation materials. Considering that they would be have to delivered from Earth, there should be chosen the lightest and the easiest to pack materials, and the most efficient at the same time (the relation of mass and thickness to efficiency is very low). It is also possible to produce such materials on Mars from local resources. Table 6.1 shows the list of properties of thermal isolators, which the author here suggests to use for Martian base.

Chart 6.1 Compared properties of insulators

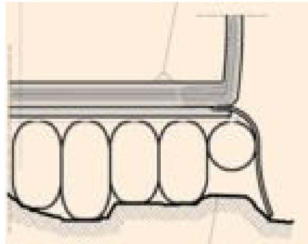
Thermal isolators	NanoPore	Microtherm (Quilted Panel)	Aerogel	Flexible Aerogel (Cryogel, Pyrogel)	Nanogel
Thermal isolation properties [W/mK]	0.004 (counted for Martian conditions 0.031)	0.017 (min. 0.008)	0.012	0.02	
Density [g/cm3]	1.7	0.17-0.29	0.1 (0.003-0.35)	0.1	0.1
Layer [mm]	2-40	3-13	20	3.2 or 6.4	25
Transparency. Color	Silver	Cream	From tansparent (usually white or yellowish) until crystal clear	White, black	Transparent, color as in the Pic. 6.67
Method of applying	Layers applied in turns	Put as a mat	Put as glass	Put as fabric	Poured in between firm divisions
Method of packing	Packed in boxes	Rolled or put in heaps	Packed in boxes	Rolled of folded (very flexible)	Poured in bags

Aerogel is contemporary the lightest insulator in the world (Pict. 6.65). Its properties are as such thanks to tiny nano-pores surrounded with equally tiny walls. Even in case of an element 1 mm thick it works incredibly: there can be a fire on one side, and the other side stays cool enough to be touched with a naked hand without any danger of burn. It is almost as light as air, but very resistant to pressing (Pict. 6.65). It has many other advantages: it is very durable, invulnerable to fire, does not absorb water, and absorbs noises well. Discovered more than seventy years ago, aerogel was very fragile and really difficult to produce. Aspen System Inc. in contract with NASA worked out cheap methods of producing and introducing aerogel. There are several products on the market now, which has slightly different characteristic. Aerogel is adequate to produce firm elements as glass, and flexible materials. Aerogel is available in form of: pellets (Pict. 6.67), fabrics (Pict. 6.68), sheets and cast forms. It may be matte, translucent, transparent, clear. It may be used in a wide spectrum of temperatures, even in cryogenic conditions. Because of its incredible possibilities, it has found its usage in astronautics. Nanogel—it is a material in form of tiny balls, which diameter is given in nanometers (Pict. 6.67). The balls are light and easy to pack—and so, easy and cheap for transportation. They also create a good thermal protection. They are not going to, however, behave as glass, but rather as a wall built from glass blocks. Such powder should be poured in adequate forms or between rigid divisions. It could also be poured on a surface and covered with resins. That way a hard, durable insulator, serving as a floor in a Martian habitat, would be created. Because their diameter is so small, pured on the ground and pressed pellets of Nanogel, compressed and covered with a mat—would also make a considerably good floor. Nanogel could also be doused with water to make ice windows.

Aspen Aerogels Inc. offers several kinds of Aerogel in form of fabric similar to a kind of blanket. They are: Pyrogel, Cryogel and Polar Bear. Cryogel (Pict. 6.68) until now has been used in astronautics to insulate hydrogen fuel tanks, which should be kept in temperatures close to absolute zero. There are also available gloves for Marsonauts made from this material. As Cryogel is highly recommended for very low temperature conditions, that is why it is recommended as insulation material for Martian base. It is produced in a form of flexible mats. It should be easy to apply it on a surface of streamlined constructions, which are preferred for such a base. To insulate windows, however, there should be used clear aerogel.

Other insulators with a very low coefficient of diffuse are Microtherm and NanoPore products. Microtherm should be thicker than NanoPore to insulate with the same efficiency, but it is available in a form of e.g. flexible quilted panels (Pict. 6.69). NanoPore is usually produced in a form of vacuum insulation panel called VIP (Pict. 6.70). It is possible, however, to obtain it in a raw product form. This way it is partially flexible, as the company reassures. In Martian conditions, where there is on one side pressure of 6 hPa, and on the other side—pressure close to the Earth's one —close to 10 hPa, its coefficiency of diffuse stays at 0.004 W/mK for a layer several centimeters thick. Both products described in this paragraph are not transparent: Microtherm is light-beige, and NanoPore silver, as it is made on the base of aluminum, so they are not recommended to apply on windows. Both are light and easy to handle, so there should not be any problems to produce them on Mars. To obturate crevices there could be used sprayed-in polyurethane foam, as it is done on Earth.

Vacuum elements filled with air are used as insulators too. Shaped ceramic stones made from resin, or other empty elements may fit in the floors or walls. In connection places there would be left weak uninsulated links, so there should be built at least two layers of fitted elements so as to make sure that each weak link is covered and insulated. There could be also used pneumatic bags to isolate the insides of a habitat from the cold surface. Additionally, adequately pumped elements could also model the floor, and even walls, to level it, as it is shown in the Pict. 6.71.



Picture 6.71: Vertical, surface habitat's floor stabilizing insulation (Kozicki 2004)

Acoustic isolators

The easiest way to make acoustic isolation on Martian base is planning silent zones as far as possible from noise zones, preferably, in separate modules. However, there should be also acoustic isolations made in the separated zones alone, so there should be used such techniques as to ensure the best possible isolation. The easiest way is to isolate rooms with buffer spaces. It is, however, connected with a considerable loss of habitable space, so there should be introduced isolating layers in division walls of the rooms. Pneumatic walls filled with air may work partially as such acoustic isolators. Their efficiency should be tested. It is worth pointing out that for acoustic isolators could be chosen materials which are also good thermal insulators, e.g. aerogel, glass polymer insulator. Both of the materials may be produced *in situ* (they are made on the base of glass). They may be used to produce light flexible materials, which are also cheap for transportation from Earth. Delivery or production *in situ* of a material widely used for several purposes is more efficient than a use of two different materials. To make acoustic isolators in Martian base there could be chosen such variation of materials, which were designed for the purpose. NASA recommends such materials, among others, as: Durette (noise absorber in a form of the blanket made form Nomex fiber, produced by Filtrations Systems), Cohrlastic (sponge-structure, elastic silicone, absorbing well any vibrations, made by Saint Gobain), Willtec Sonex (melamine foam, a good acoustic isolator, sold by Pinta Acoustic), Solimide (a foam, absorbing noise, made by American Micro Industries), Bisco HT-200 (thin mats made from impregnated silicon, a very good acoustic isolator, made by Rogers Corporation)[11].

Membranes

In Martian habitat there should be assured artificial atmosphere similar to the Earth's one, to enable people to breath and function normally. This atmosphere is different from the one on Mars, and must be isolated from it. There should be lowered to the minimum any amount of gas leaks, such as nitrogen and oxygen, which are the main components of the breathable atmosphere for people. On the other side, there must no be any leaks of humidity trough the outside barriers of the

11 Information source: http://hefd.jsc.nasa.gov/acousticsmaterials.htm.

base.

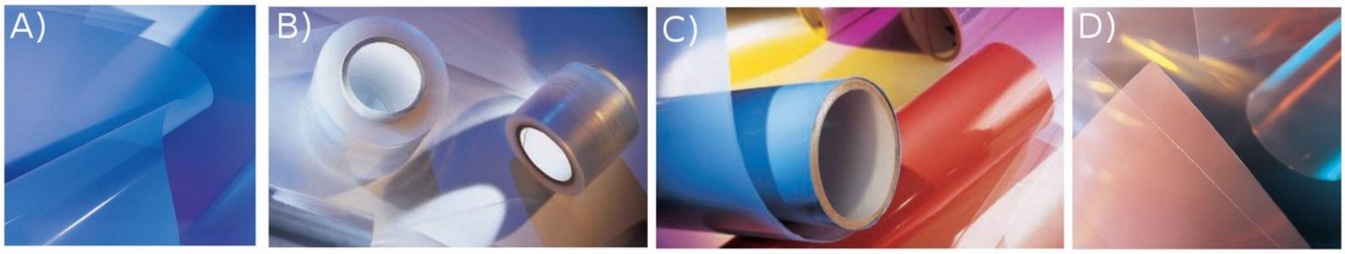
Any kind of material creates a kind of a barrier for gas and water. In Martian habitat there should be used those materials which let through the least amount of them. Thanks to this the inside atmosphere should be stable, and there should be required only a small amount of its components to complement it. This should lower the cost of maintenance of the base. The best barrier for gas there are thick layers of heavy and dense materials, made form metal etc. Transportation of such materials from Earth would be expensive, and their production *in situ* would be also difficult and expensive. That is why there should be seriously considered, to ensure the best effect, the lightest possible materials. The answer to such requirements are membranes. They are usually in a form of very thin, and not dense, plastic foils. They are flexible and may be rolled for the transportation. Their efficiency as a barrier is superb. There are many of such materials available on the market (Saechtling 2000). The analyses conduced by the author enabled her to choose those, which seems fit best to create good obturation of Martian base. Chart 6.2 shows a comparison of the barrier properties[12].

12 The data comes from fact-finders of Goodfellow Corp. (goodfellow.com) and Saint-Gobain (fffna.saint-gobain.com), the world-wide known company which specializes in production of plastic products.

Chart 6.2: Permeability of membranes comparison

Name	Permeability of gas-assessment	Permeability of gas-data [x10^{-13}cm^3.cm^{-2}s^{-1}Pa^{-1}]	Reaction when watter applied-assessment	Reaction when watter applied: p-permeability [x10^{-13}cm^3.cm^{-2}s^{-1}Pa^{-1}], a-absorption	The lowest work temperature [^{o}C]
		0,2 N_2			
		0,6 O_2		p=170	
ETFE	+/-	3 CO_2	+	a<0,03	-200
		0,04 N_2			
		0,1 O_2		p=150	
ECTFE	+	0,4 CO_2	+	a<0,02	-200
		1 N_2			
		3 O_2		p=13	
FEP, (PFA)	+/-	10 CO_2	++	a=0,01, (a<0,03)	-250
		0,07 N_2			
		0,002 O_2		p=300	
PA, (MXD6)	++	0,06 CO_2	+	a=0,31	[-]
		0,004 N_2			
		0,03 O_2		p=0,2	
PCTFE	++	0,1 CO_2	+++	a<0,01	-240
		0,004 N_2			
		0,03 O_2		p=100	
PET	++	0,2 CO_2	+	a=0,1	-60
		0,03 N_2			
		0,1 O_2		p=400	
PI	++	0,5 CO_2	+/-	a=0,2	-270
		0,3 N_2			
		1,7 O_2		p=16	
PP	+/-	6 CO_2	++	a=0,03	-60
		0,001 N_2			
		0,004 O_2		p=7	
PVDC	++	0,02 CO_2	++	a=0,1	[-]
		0,03 N_2			
		0,03 O_2		p=250	
PVD	++	0,2 CO_2	+	a=0,04	-60

Many of those foils are resistant to low temperatures that occur on Mars. Thanks to this there would be no problems during the assembly. In the chart, there was taken into consideration the carbon-dioxide permeability. Is should be pointed, however, that the thickening of this gas in habitat would probably be very similar to that outside, and that is why permeability of CO_2 is not an important factor for the membrane's choice.



Picture 6.72: Plastic foils: A) ECTFE, B) PVDF, C) ETFE, D) PFA (DuPont)

Membranes that are produced as nanoparticles composites have got much better properties. Their oxygen permeability can be lowered even three times. Their structure is more clarified, so they can be thinner, and as the consequence—more flexible. Nanoparticles may influence also the durability of polymers and co-polymers. An example of such membrane made with nanoparticles is PA MXD6. Most of it properties is similar to those of other nylons, but because of the nano-technology, it permeability of gas is exceptionally low (Lan an others 2001). When the most important factor is small weight of material, there should be chosen one foil PCTFE. When the most important factor is exceptionally airtight material, there should be chosen several membranes, which put together would create a several-layer foil. To make it there could be taken e.g. PA MXD6, which oxygen permeability is exceptionally low, PVDC, which is the barrier for nitrogen, and PCTFE, which keeps water inside the best. Not all of the foils may be combined or coated. A specialist is required to plan the details of such a multi-layer material.

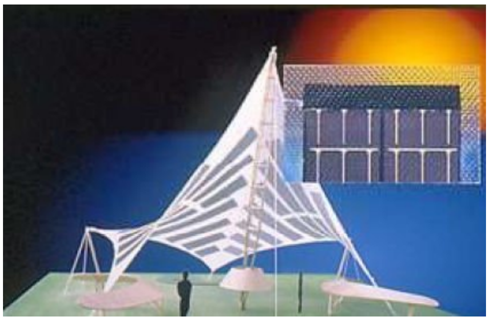
All of the shown in the Chart 6.2 foils are transparent, their permeability of visible light reaches even 96% (PFA, FEP[13]). They are good enough to obturate transparent barriers. In the Pict. 6.72 there are shown some of the membranes described here. Most of the shown membranes are almost inflammable or fire-proof (V0), except PET, PA i PP (HB). The foils are very often anti-static and resistant to pollution as dirt, Martian dust, mould, bacterias. Thin foils made from materials of tiny density do not characterize with incredible mechanical properties. Some of them, however, are resistant enough to stretching (PI[14] , PVDC, PET), and others are stretchable and very difficult to perforate (FEP, ECTFE, ETFE). This durability is obligatory practically only in case of pneumatic constructions, when foils are the construction's element. When there is very high resistance to severance there are fiber reinforcement required. The strongest fibers are, among others: Kevlar, Nomex, mylar, Vectran, glass, carbon. Those fibers, creating a well woven net coated with resin made from a given polymer or co-polymer, create a very resistant composite. Fibers do not influence significantly flexibility of the foil, however, they cause lower permeability of visible light. Between the layers of the high transparency foil there

13 Pneumatic construction made from FEP foil is shown in the Pict. 6.11

14 Polyimide is used to built among others Sun concentrators for Space thermal propulsions (Moore and McGee 2001).

might be inserted flexible solar cells to collect energy required for Martian base during sunny days (DuPont 2007) (Pict. 6.73).

The specialist membranes may be produced only on Earth. It is possible to make polyethylene only from local sources on Mars (Zubrin and Wagner 1997, p.245). It is not a type of incredible barrier properties material, but it could be used to obturate the base. Polyethylene may be modified or added as admixture to improve its mechanical and protection properties, there might be also produced co-polymers with its dominance. Gas permeability of co-polymer E/VAL is almost minimum, net-reinforced polyethylene PEX, co-polymer PE-VLD is very difficult to severe, and it is stretchable more than 900% (Saechtling 2000).



Picture 6.73: Solar Pavilion, designed by Nicholas Goldsmith (Ron Dabick)

Conclusions for architect

Martian habitat has to be equipped with three kinds of insulators: anti-radiation, thermal, and protecting it against gas-leaks and humidity-leaks from the artificial atmosphere inside. There are different types and they should be used in different ways. They may influence significantly a look of the habitat—its form, coloration, outside structure. Thus, architect should take them all into consideration, and decide what kinds of isolation should be applied. There may be chosen isolators of each type to obturate also division walls and windows.

1. Martian habitat should keep its habitants safe from the radiation pollution. Thus, an architect should design also barriers against the Sun and Space radiation. All of the habitat's rooms should be protected against the Space radiation; the shelter should be protected against the Sun radiation. The shelter should be designed to keep the habitants safe during the time of explosions on the Sun. The Space radiation is weaker, so effective barriers create enough protection.
2. A good anti-radiation barrier could be made from: water tanks, ice-barriers, a layer of regolith, regolith blocks, resin enriched with hydrogen (e.g. ICI Fiberite 934) demron sheets.
3. Demron sheets may be used as temporary curtains for windows and greenhouses.
4. Liquid water or ice-blocks let through the Sun-light well, and so they are recommended as windows or transparent walls, and at the same time, as a good anti-radiation barrier. Smaller transparent elements, like smaller windows, could be made from isolators delivered for the purpose, e.g. profiles, shaped stones, made from resin enriched with hydrogen. There could be also used transparent foils, of designed thickness, made from light elements (e.g. PE).

5. To ensure more stable temperature for the whole base there should be suggested a thermal insulator, which would keep heat inside the base.
6. There are suggested some thermal insulators for such a base: aerogel (hard, flexible or pellets), and quilted panels Microtherm or Nanopore. Aerogel is the lightest possible and the best thermal insulator in the world. It may be used as flexible fabric, poured pellets, or pellets suffused with resin, or as firm panels. Panels are excellent for windows. Nanogel (pellets) may be poured between two firm walls. It is much more comfortable to use. Cryogel (fabric) may be used to apply as a very thin and light insulator on the walls.
7. The habitat should be air-tight, and so there should be planned an air-tight layer which should be able to keep gas and humidity on one side. The best materials to fit the purpose are light and flexible, thin membranes, made from plastic. These foils may be colored or transparent. They could be used to keep air-tight transparent barriers and windows.
8. In pneumatic constructions there could be used membranes reinforced with fibers to make them more resistant to mechanical damage.

6.1.7 Installations

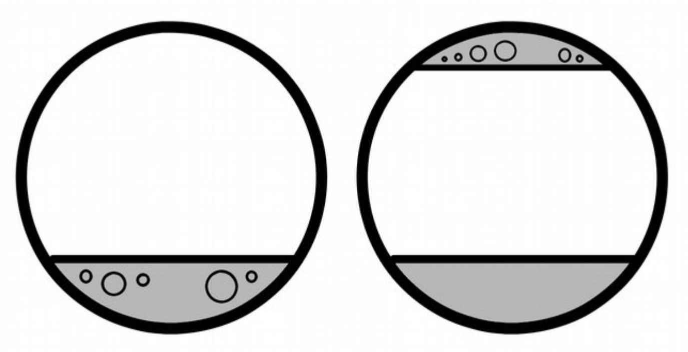
Installation and architecture of base

Installations, which should be fitted into the base, may influence more or less the whole architecture of it. There should be taken into consideration and planned fixtures and technical space. Architect, of course, should consult specialists; however, the design of fixtures may be planned accordingly with the whole architectural vision of the base. The author here decided to elaborate two types of planning it: hiding fixtures behind the walls, or as aesthetically exposed fixtures. Every solution here has its advantages and disadvantages. In the first case it is required to leave enough space for the walls/covers, which in the end would occupy more space than the fixtures alone. What is more, this solution may influence badly the availability of fitting fixtures in flexible space of the habitat, when they could be fixed in some walls only. The restrictions would influence functionalism of a room as to the limited places for e.g. sockets, pipes etc. However, hiding fixtures would influence immensely their safety, as it would be more difficult to damage them by accident. What is more, there could be used to hide them places, which are ergonomically difficult to reach for people, e.g. under floor in the cylinder-shaped module (Pict. 6.74).

In the second case the fixtures would be exposed. Here, it would be much easier to install fixtures more optimally and functionally. The sum of fixtures would occupy much less space that way. Fixture ducts may create decorating elements in the base. Some interesting solutions are suggested by AirDD, among others (Pict. 6.75).Their products are light and easy to pack, flexible, and fast and easy to install. That is why they should be excellent for Martian base to build wiring and ventilation piping.

Pipage are the next type of fixture that could be exposed. Water tanks may even become elements of small architecture. They may create closed mini-pools, lit tanks or walls. Pipes to connect then may be made from transparent profiles.

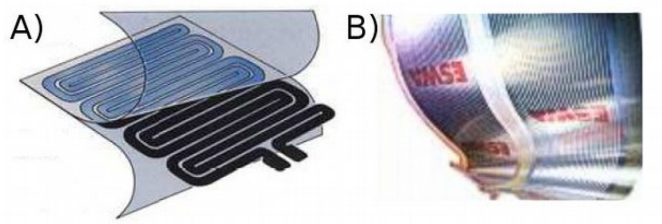
In both cases, exposed or hidden, fixtures should be protected against accidental damage, and at the same time, easy to reach in case of damage. They should be also easy to find, that is why ducts for specific fixtures could be tagged with characteristic colors. The covers of fixtures should be light and easy to move, and at the same time appropriate for the type of fixture (e.g. bulky fixtures should not be hung in pneumatic structures etc.). The smaller total bulk of fixtures, the lower costs of its transportation from Earth.



Pict. 6.74: Examples of hidden fixtures in the construction built as a horizontal cylinder

Pict. 6.75: Pneumatic fixture supporting AirDuct (AirDD)

Heating fixtures may be of three types: heating plates, heating air in air-conditioning, heating foils. Heating plates are suggested for metal, one-element module of NASA DRM (Mars or Bust 2003). It is a traditional heating system. However, there are many reasons why it is not the best type of heating for Martian base. The layout of plates should be considered carefully and planned to the detail. It should be compatible to air-ventilation points, because air in the habitat will be almost still due to the lack of natural ventilation. The closer to the ventilation points, the more effectively heat would spread around the habitat. The layout of such plates needs to cooperate with the layout of the equipment (especially the pieces of it that create heat), and furniture in the base. It created the need of restricted furniture layout in the base. Thus, it is not recommended for flexible habitats. Heating plates are comparatively heavy and require the whole piping system to carry hot water. Any leaks would be most dangerous. This type of heating is suggested as comparatively expensive and troublesome.



Pict. 6.76 Heating foil: A) the layout of layers, B) The photo of the product (Backer Elektro)

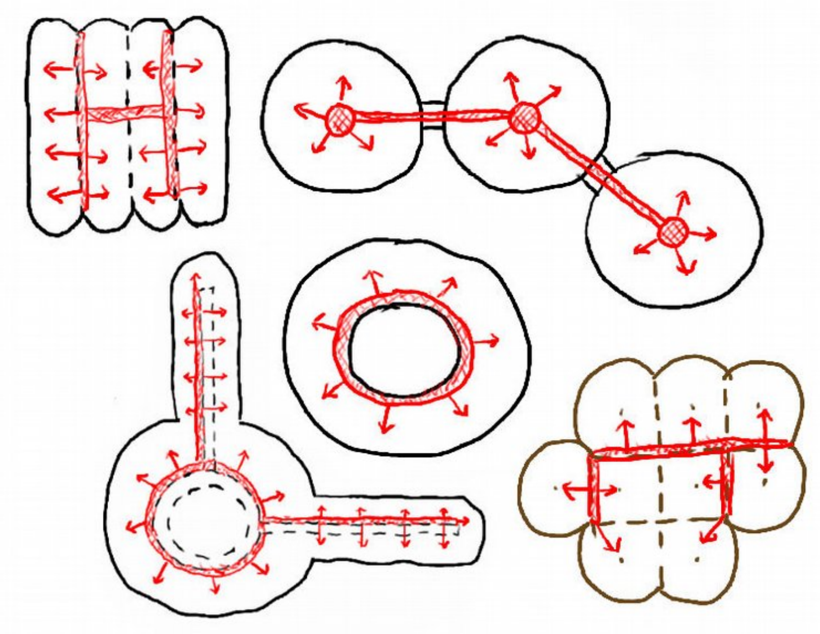
Air-conditioning heating system looks much more reasonable here. The whole heating system would be hidden and would not restrict configuration of furniture in flexible rooms. Such a system would be manipulated to apply temperatures for specific rooms: lower temperature where there would be equipment creating its heat, individual operating of heating in private cabins. Its disadvantage is that forced airflow is considerably weak, so the warm airflow would be too slow. When oxidizing and heating atmosphere would be made by separate systems, the warm airflow would require its additional system, mostly pumps.

Another heating system that the author analyses here are heating foils. There are used on Earth to heat walls, ceilings and floors, and to heat iced roads too. They ensure considerably even heating flow thanks to continuity of the installation. That is why they are excellent to heat air-tight rooms where the air inside is almost still. The most important advantage of such a system is the small weight of installation. Heating foil is flexible, easy to pack—they may be rolled and folded. They are suggested for streamlined walls, whivh are going to be dominant in Martian base. Heating foil requires fitting electric wiring between isolating layers of foil. That wiring is very thin—10 to 100 microns—so they are in a form of metal cuts of foil (aluminum, copper, brass) (BackerElektro 2004). They usually create a dense net (Pict. 6.76). They might be also applied with larger gaps between them. It is important for barriers that they should stay transparent and let in the sunlight. Windows, skylights and walls (e.g. in a greenhouse) are not going to touch cold Martian ground, but thin atmosphere, which does not take away heat as fast as the thick atmosphere inside. That is why the wiring does not need to be dense. That way the percentage of obscuration would not be too high. Foils, which are usually used on Earth for such purposes, may be substituted with clear foils with a very high lever of light permeability, and, at the same time, they could support construction (encumbrance transportation) and keep insides air-tight—mostly in pneumatic structures. Heating foil seems to be safe to use on Mars. They do not require any pumps or other additional equipment. They are low energy consuming products.

Conclusions for architect

The way of building fixture ducts and the choice of systems may and is going to influence the whole architecture of base. There should be suggested one solution in the plan: hiding the installation, or its aesthetic exposition.

1. The layout of technical rooms and systems of fixture ducts should be introduced in the functional system of base in such a way as to make the length of installation as short as possible: the main installation systems and the pieces leading from the main systems. The author here suggests some possible layouts (Pict. 6.77). Those solutions are made to lower the costs and the weight of the whole installation. In case of failure only a small piece of base would be cut off the medium, what influence positively the safety standard of fixtures operating.
2. In case of coated cables their distribution layout should be planned aesthetically. Elements of installation systems may become forms of small architecture (e.g. pipage), or create colorful decoration (air ducts).
3. Cables of different installations may be tagged with colors for better recognition of those systems.
4. A type of heating system influence considerably the planned habitat space, e.g. limits the layout of equipment and furniture. Heating foils seems to be the best, and the least invasive in flexible spaces. They are recommended by the author here for Martian base because of their small weight, easiness of installation (fitting, cutting), end economic advantages.

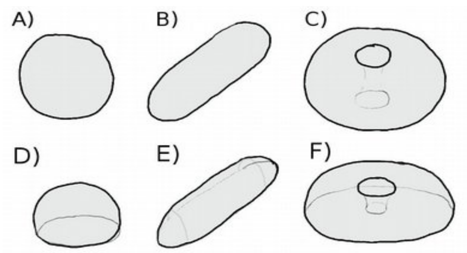


Pict. 6.77: The suggested solutions of fixtures ducts on the outlines of bases of different space structure

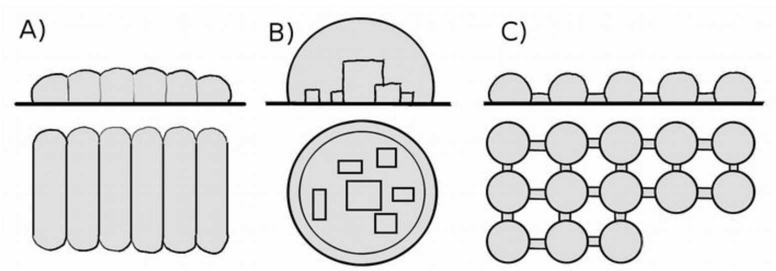
6.2 Form

The outside form of Martian habitat is dictated by the pressure differences between the thick, artificial atmosphere inside the base, and the very thin Martian atmosphere outside the base. Gas imprisoned inside will be pressing on the walls. When gas is pump inside a flexible tank, it is only natural that it becomes spherical. That is why any optimal pressure dispersion in Martian base may be ensured by streamlined, oblong forms. In other cases, in other forms, there would be created uneven pressures in different places, which can lead to wearing off of the construction and materials, crevices etc. That is why there are suggested for Martian base: sphere, cylinder, torus, alternatively cuts of those forms: dome, arch, a piece of torus (Pict. 6.78). Construction should be oblong, streamlined in places of border between Martian and artificial atmosphere, so on the surface of the base. The author here suggest three solutions which answer those needs: adjacent forms, a complex of buildings under one cover, or a multi-modular complex (Pict. 6.79, 6.80).

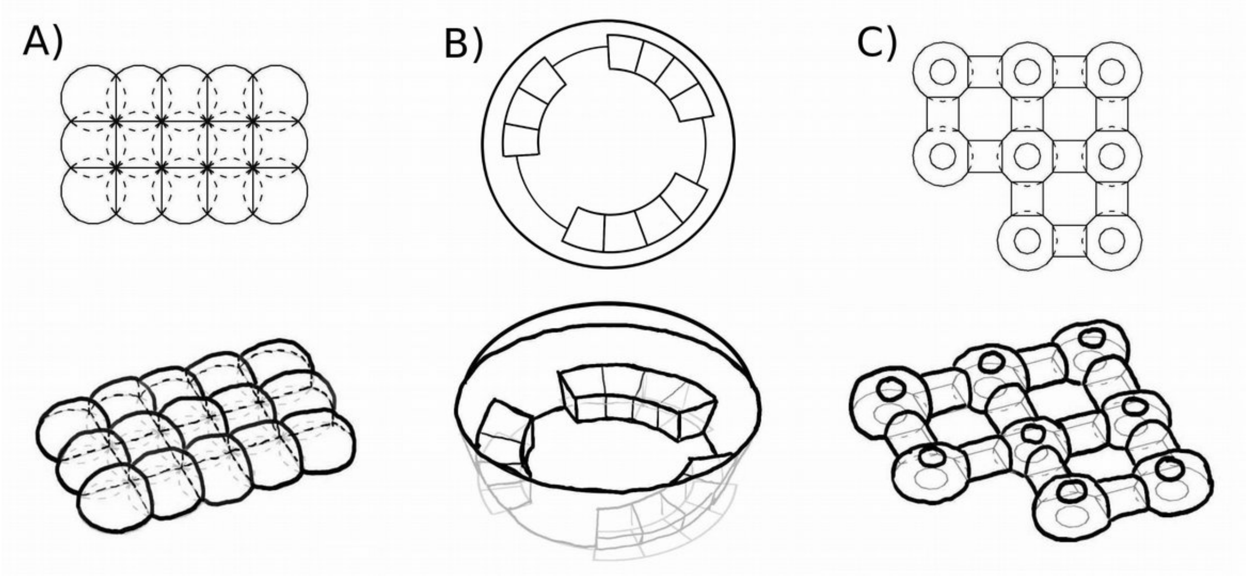
Adjacent forms are created by putting together basic sphere-like forms and connecting them into one compact structure. The main advantage of this solution is that with the use of one model, there can be created variations of complex structures, which configuration would be dictated by optimal function solution. Any required spatial changes would be introduced easily thanks to simple method of connecting modules. Adjacent forms create 'live' structure, open for changes with habitants' requirements. A surface to connect modules is flat. Even a cuboid could be created by connecting many of such building modules. This shape is familiar to people from Earth, so it could comfort habitants of the base. Adjacent forms create large total space of the habitat built that way, where people would be able to move around easily and fast, because modules would be divided with a flat wall only, with doors installed. It is worth remember, however, that the dispersion of pressure would not be optimal there, when there would be left openings between modules.



Picture 6.78: Basic streamlined forms: A) sphere, B) cylinder, C) torus; D) dome, E) arch/vault, F) cut of torus



Picture 6.79: Outlines of different solutions with the use of spheric-like forms to plan Martian base: A) adjacent forms, B) a complex of buildings under one cover, C) multi-modular complex



Picture 6.80: Concept outline of Martian base: different combinations of spheric-like forms

It is especially beneficiary solution for constructions built in the open space. It is so, because the surface of the walls that should isolate the habitat from Martian atmosphere may be in this case the smallest one. In case of pneumatic constructions, any changes introduced to shape forms would not be a problem, because those structures come back to their natural form naturally after any moves. Moving around firm constructions is limited, because they have flat or streamlined surfaces fitting planned places only, so they cannot be put freely anywhere. Additionally, any possible changes could be introduced freely only when anti-radiation isolation would be also flexible.

Complex of buildings under one cover is created by buildings of any shape installed under one streamlined coat. Such base should be shaped as a single oblong form. One outside coat may hide a village underneath. This coat creates a kind of barrier between the inside and outside environment, and has to be made according to all of the requirements for Martian base. As about the buildings inside, they could be made with the use of almost any available technology. The advantage of such solution is that there is created a very flexible habitat under the coating, which might be used freely. There is no problem with using technologies that require water in its liquid state. Buildings may be shaped freely, including cuboid—easy to build and similar to houses on Earth. However, the coating would be a huge structure, and building it would be a real challenge, as well as its transportation and installation. Zubrin and Wagner (1997) think that it is possible to build a coating even 50 m in diameter, using modern technologies. In case of appearance of any weak points in such a coat, the whole base(or at least a considerable part of it) would be in danger . Repairing would be more or less difficult, depending on its construction. However, Zubrin and Wagner (1997) think that in case of considerably small perforation, gas leaks would be so slow from such a large dome that it would leave time to repair it and make it airtight again soon enough. The larger construction, the more difficult to build it with precision and install it *in situ*. Costs of building it would be also considerably larger. However, as the author here points, building habitat under such coating would be much cheaper, when done from local resources. Their lower quality would not be disturbing. Any damages in those buildings would not be a great loss because their reparations would not mean transporting expensive modules and elements from Earth. A complex of buildings under one coating is a solution suggested for development in natural (craters) of artificial depressions on the surface of Mars, because the coating would have the smallest possible surface then (it should cover the habitat only above it, because buildings would be surrounded by rock).

Multi-modular complex is a solution using several, considerably small constructions. A multi-modular complex would be created by connecting them with airlocks. It is the safest solution. In case of serious damages small modules would be replaced with new ones considerably cheap. For the time being such damaged module could be closed and left then without any serious influence on the rest of the habitat. Modules could be connected according to different plans and their moving would be considerably easy. The development of base would be easy, and required only connecting new modules. The larger disadvantage here would be the need of using airlocks. Those are the additional elements, which should be delivered from Earth. Apart form this, moving around the base would not be easy because of the airlocks. Flexible airlocks are light so their transportation would be cheaper. However, firm airlocks are more comfortable for the users. It is a good solution for excavated constructions, where an airlock could be built in a form of a short passage.

Conclusions for architect

Each form elaborated above has its advantages and disadvantages. Only when there would be decided for Martian base an exact area for a habitat, leading functions and the type of construction, then there would be possible to decide which solution is the best one. Every one offers some freedom for the designer and allows creating many different spatial solutions, which are limited only by the architect's creativity.

6.3 Function

Factors influencing functional solutions for Martian base

There could be extinguished three main factors influencing functional solutions for Martian base: the inhabitance program, construction solutions and human factor.

The inhabitance program should include key information specifying:

- the leading role of base (industrial, housing, science)

- the number and type of habitants (laborers, scientists, families)
- the type of habitat unit and expected size of the base

The program may specify also changes in the base operating (in the beginning there would be scientific researches conducted there, next—industry would start). The exact points of such a program can only be speculated for now. Nowadays several Space Agencies work on shipping people to Mars to conduct scientific researches in there. That is why it seems that the most real scenario is to settle a science base on the Red Planet. Such a form of exploration would allow gathering knowledge only, without any financial profits. There are different resources on Mars and its satellites, which exploitation could be profitable in future. Low gravitation should make it possible to lower costs of exploitation of resources. However, then it would be crucial to build there industrial bases. Corporation 4 Frontiers (see: Tab. 1.1) set as a goal a colonization of Mars. It would require building a base which leading function would be housing. Work functions would be different there, and work places would be planned to keep the base profitable.

A leading function of the base influence the choice of people that would live in there—laborers, scientists, families. Only after detailed researches it would be possible to decide the number of habitants. It is very difficult to decide here how many people there should be. It might be assumed that such a base is a habitat unit, which could be inhabited by several to a hundred, and even more people. Larger numbers of people inhabiting such a place would modify it into a colony; a colony would require more complicated structural function, similar rather to a town, than to a base. When there would be less than several people—it would be rather a station (it would function as a house with a studio to work). There would be also possible that such a small number of people would only be required there for a start phase only.

Besides a problematic leading role of the base, and the number of its habitants, there is also a problem of the type of habitat's unit and expected size of the base. Depending on the fact that it would be a single base, or one of several logements (what would be a consequence of dispersed rich fossils sources and bases built in vicinity of those). The smaller base and the larger number of habitants, the more difficult it is to find an optimal solution for its functionality. A base is not a typical habitat, there is no a correspondent building on Earth. Depending on the number of habitants and the size of base, its model would be planned starting from a household, and growing into a town. There is a huge gap between those two concepts. Martian base may be compared to polar stations. Those are temporary habitats for several (two, three, or even a dozen) people to work and live there together, in extreme conditions. However, one unit of people do not stay there longer than for a few months, there are no families there, and buildings are not connected with each other with any kind of airlocks. The function of such polar station is firmly decided—usually it is a place to conduct researches, it is sometimes connected with a military base, sometimes it is also a place to stay and sleep for a short time for tourists. A base would be a universal urban unit on Mars. The number of habitants would point to a kind of a village. A complexed and highly specialized technical infrastructure will create the image of a city. There will coexist together houses, laboratories, entertainment places and greenhouses.

The construction's solution defines:

- how the base will be localize on Mars (on the surface, underground);
- what building units will create it (modules of one type or pairs of types, single large units);
- what forms and sizes of buildings are acceptable;
- system of connections between building units (typical hermetic doors, airlocks, feed-halls)
- shape of insides (cross-section of a circle, rectangle, hoop, irregular);
- space of insides (one large room, many small oblong rooms);
- number of floors and their construction's forms and solutions (pyramid, entresols, closed floors, patios);
- places of exits to the surface (close to elevators leading outside, on the perimeter of the structure);
- possibility of lighting with the daylight (possible windows' arrangement, skylights, vertical or installed in the roof transparent and clear divisions).

All the above factors will influence considerably the functional plan of Martian base. However, the important clause here is that the way of placing functions may influence introducing changes in the construction's solutions, e.g. building smaller or larger modules, a different arrangement of windows, etc.

Human aspect is very important in case of Martian base, which is supposed to serve people for a long time. Ensuring physical and psychical comfort in such a place may depend on, among others, good solutions of the functionality.

There could be distinguished four basic functions in Martian habitat: housing, working, recreating, and growing plants. Each of the functions will require specific group of rooms. It is really difficult to decide now a complete unit of rooms for every function.

As a part of housing function there should be surely space to live anticipated. There are recommendations for each crew member to have his own private cabin in extreme conditions (Stuster 1986). Thus, the number of private cabins should be at least the same, as the number of habitants. There should be also some emergency rooms planned. They would allow people to move into in a case of any kind of dangerous failure in a private cabin, or when someone would feel the need to change place, because of a conflict with neighbors. There are possibilities of conflicts among crew members, that is why it is worth anticipating two housing zones. That way conflicted parties could stay at a distance (Stuster 1986). There should be planned a large enough space for housing according to the rule: the longer space-mission, the larger private space should be ensured for each crew member (Stuster 1986). It would be recommended to plan every room in different shapes, limited to the same space. Distinguishing anybody would influence negatively a group (Stuster 1986), and escaping modularity would allow people to personalize their private space and create emotional connection with such space. There should be planned rather one room for everyone. However, with the use of different division elements in one room it would be possible for a crew member to create a kind of a flat with several rooms, limited to available space there. In case of a large group of habitants, the base could be designed on the well known in urbanism atrium plan. This plan is known as the best for organizing neighborhood and creating good group connections (Schneider-Skalska 2004, s.107). Apart from this, because of economic reasons, there should be Jack and Jill bathrooms and toilets, for at least two crew members. Similar grouping should possibly be planned for small messes. Integration will be probably imposed on the habitants by neutral factors.

It is difficult to decide now what work-places will have to be planned in Martian base. It is possible to anticipate, apart from that that the dominant function of the base there will be science laboratories, they could be integrated in one zone. There are conducted all of the science researches in one room on orbital stations. The author here could not find any conflicts emerging from such a conflict in any sources for this work (apart the matter of noise which accompanies the usage of many parts of equipment at the same time). In Martian habitat there would be recommended division specialists at least with some kind of sliding walls, which would be shut, when the work required more concentration, or would be open, when the work allowed or required social contact, consultations, thought exchange. In working areas personalization of places is recommended if possible (Stuster 1986). That is why there should be planned working places for every assigned person to work in one place. The comfort connected with having individual working places influences positively the workers' wellbeing, mainly because they will be going to Mars to work. Their work is going to play a very important part during their time on the Red Planet. The second type of working places, which are going to be planned on Martian base, are those connected with plants—growing, segregation and processing (milling grains, making jams and pickles etc.). The best option would be to plan those places in close vicinity to growing fields, technical fixtures, kitchen and food store rooms.

There should be planned variable recreation facilities in different places on Martian base, preferably located close to the main communication alleys. Restricting them to one module or zone is not a good solution, because recreation can be divided into relaxational and active. The former one requires silence and calmness, the latter one may be accompanied with noise. Apart from this, some types of recreating places should be planned closer to housing zones (e.g. a gym, when after doing exercises, a shower is needed), others—far away from those zones (noisy party places, cinemas).

There could be considered different solutions in case of agriculture. There should be much area designed for main plants growing to ensure food for all of the habitants. There could be planned one large zone for this purpose, for example in the center of the base or on its perimeters, where would be the best access to daylight. A good solution is for housing zone to be close to gardens; habitants could have windows offering a view of green plants. Contact with nature is very important for people, it brings them calmness and happiness. Thus, the larger part of housing area is close to gardens, and visual contact may be unrestricted, the greater is psychical comfort of habitants of the base. Relaxational facilities, as a library, may be adjacent to gardens, separated from them with a large, clear barrier. The author assumes here that for the safety reasons contact with plants will be restricted, to limit any possibilities of fungus and mould transportation into housing zones. That is why only closed fields for growing food are planned for such a base. However, it would be possible to grow plants in private cabins. They should be kept in closed tanks. Larger tanks with green plants could be planned as elements of public places, mainly in recreation areas. They could be small biospheres to filtrate carbon-dioxide in a room, supplying oxygen. Special membranes should be chosen to build such tanks, to lower costs and ensure their efficiency. People in safe suits should be able to reach those tanks to take care of plants, so the tanks should be connected with main growing fields with passages.

Flexible living area

Functional plan is very important in case of small modules, which are characteristic for existing Space habitats. Their small space requires packing tight everything inside: all of the crew members and scientific laboratories to conduct many different researches. Divisions between rooms are firmly planned and furniture must fit the small space it can occupy. There are no possibilities to introduce changes or corrections to improve the insides, which would be welcomed by habitants during the mission, to improve psychical and physical comfort. Architect must anticipate any possible discomforts, because there would be no room to introduce changes. Despite great efforts of architects, all those Space habitats are incredibly tight and uncomfortable. There have to be applied strict rules, which assure only basic creature comforts. In case of larger habitats available space is much bigger. There is, thanks to this, possibility to make the best use of it; a good start is a default optimal functionality plan to ensure people would be able to introduce changes later on, which is unavoidable. Martian base is a large habitat in extreme conditions, intended for a long stay for people, whose psychical and physical comfort is treated with priority. The author is sure that first of all flexible living area is crucial there because of those priorities. Such area should allow planning there different functions, in many configurations and reliance lines. It enables people to introduce functional changes simple and easy; it also allows people to introduce diversions in everyday environment, and it is easy to adapt for special occasions.

Planning such flexible living area is possible even now. When the final habitat program is be ready, there will be planned initial default functionality scheme. It should be well considered, however, possibility to treat it with some freedom. It is worth preparing several possible plans for the same space. It should be assumed that even a plan best considered may not be suitable for Martian base. This is the consequence of the fact that it is very difficult to anticipate behavior and needs of all the people who are going to live on Mars. The case here is the comfort of moving around in lower gravitation conditions, as well as creation of social behavior, which is going to be subjected to prodigious changes, especially when crews will change (e.g. from one mission to another). Optimal functionality system will alter in time, accompanied by possible changes in the main base program, development of the base, its expansion, new technological solutions (e.g. in communication system inside the base). Every square meter of habitable space on Mars is much more expensive than anywhere on Earth, even if ISRU technology is responsible for many tasks. That is why it is crucial that no space would be lost. Leaving an old base and building a brand new one (e;g; because of wrong communication system in the old one) would be adverse financially and spatially. That is why Martian base should not be planned as a firm functional arrangement. **The habitat must be planned as flexible space**. Then, and only then, it may survive the time trial. It is the only economical solution for a base which pretends to become a human-friendly habitat. It is impossible to anticipate the future, but it is possible to prepare for it. The author is sure that it is crucial to design Martian base as architecture adaptable to its functionality. The use of small, tight modules with firmly fixed walls, as it is suggested for first manned missions to Mars (in case of Mars Direct program and DRM based on that) is rather only poorly suitable. Arranging a net of such modules into a base seems to be rather unfavorable in terms of: percentage share of communication functions, a nuisance of having to go through all the airlocks, and the general discomfort of moving around in such a habitat. It would be difficult to ensure psychical and physical sense of comfort.

To create flexible space the construction should be designed adequately. Some of the functions in the base may require specific solutions. The author enumerates below the influence of functions onto construction, form and the insides of Martian base.

- Flexible space requires the less possible number of firmly fixed construction elements, mainly walls and studs.
- The simplest division of conflicting functions is to set them in separate building units—e.g. in modules connected with airlocks, or in separate, distant parts of habitat.
- The desire to plan windows in most of the living rooms requires construction solution to make it possible. It limits the shape of habitat.
- The type of communication may influence the form of base, its modular arrangement etc. It applies especially to communication fast-lines, which requires additional specific construction solutions.
- Some functions require specific solutions, e.g. greenhouses, which should be well-lit, or shelters, which should be equipped with exceptionally good anti-radiation layer.

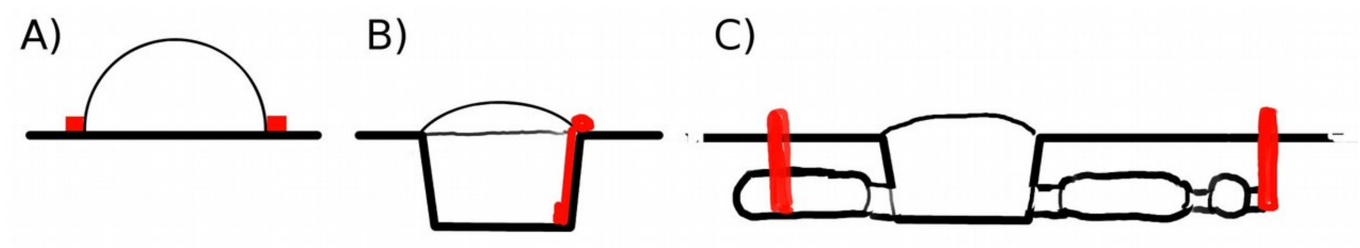
Communication

The basic element of developing settlement structure is its communication arrangement. It should enable habitat's development, and support it. The communication arrangement in settlement units on Earth is a net of open roads. On Mars whole communication of the base should be hidden in hermetic spaces—as it would be in buildings. Forcing people to move around the parts of base in space suits is an unacceptable hindrance. People should change clothes then and take their time to adapt to different pressures. Martian base would be compared to a city compressed into a building. Communication arrangement of the base should compromise a well-known net of roads and corridors of multi-functional building. It is impossible to anticipate now the optimal way of transportation and arrangement of communication for a settlement unit on Mars in future. However, introductory analyses of the problem may give directions to future researches.

The only function which should be considerably strictly planned is communication. It introduces order and harmony. A settled arrangement of main communication ducts should be simple and clear to simplify orientation in the base. Such imposed arrangement of transportation should be easy to remember to rationalize moving around the base for people. It is especially important in a flexible, possible to be changed space reserved for other functions, and minor roads. Main communication ducts have to cumulate traffic from minor ducts and lead to evacuation exits. That is why they should be wide and considerably short, to occupy less habitable space and ensure the fastest possible evacuation. The optimal solution is for each point in the base to connect with two main evacuation ways (Puerto Rico Group 1989). In an oblong building it is provided with a straight road, in other cases (a building on a circular plan or multi-modular structure) a roundabout way is suggested: leading on the perimeter of circle, triangle, rectangle etc. Ducts of minor relevance should be rather planned with some diversification to distract the monotony of closed living environment.

Designing communication ducts depends on the form of a base. If the base is one large building, then it is planned on the open space. It allows free planning of communication scheme, and exit airlocks may be set due to the functional design. In case of adjacent modules the communication scheme is partially restricted—entrances may be set only in common walls. Still, it gives some freedom to plan habitat's communication scheme. When modules are separate elements of a base, with individual airlocks, the plan is fixed firmly then. Points of entrances/exits are strictly located and the plan depends on such a scheme.

Communication elements that may be planned inside Martian base are: airlocks (entrance, exit), roads (different types), crossings, public squares, stairs, ladders, ramps, bridges, footbridges etc.



Picture 6.81: Different kinds of exits to surface form hermetic Martian base:A) on surface (typical airlock)and B,C) underground (communication route inside habitable space or independent)

Airlocks: There are airlocks of two types: entrances (to the whole object) and passageways (between modules). The number of entrances depends on: number of habitants, safety rules, spatial structure of habitat (Pict. 6.81). Some of those airlocks may be designed to allow going out to the surface and to go through to specifically connected Martian vehicles. The more of such airlocks, the higher level of safety standard: more people can leave or enter the object at the same time, and a loss of one of the airlocks due to failure is less severe. However, installation of airlocks is expensive, as they require a special changing room with specific equipment, and rooms to get ready to go out to the surface. Every module should be equipped with at least two such airlocks.

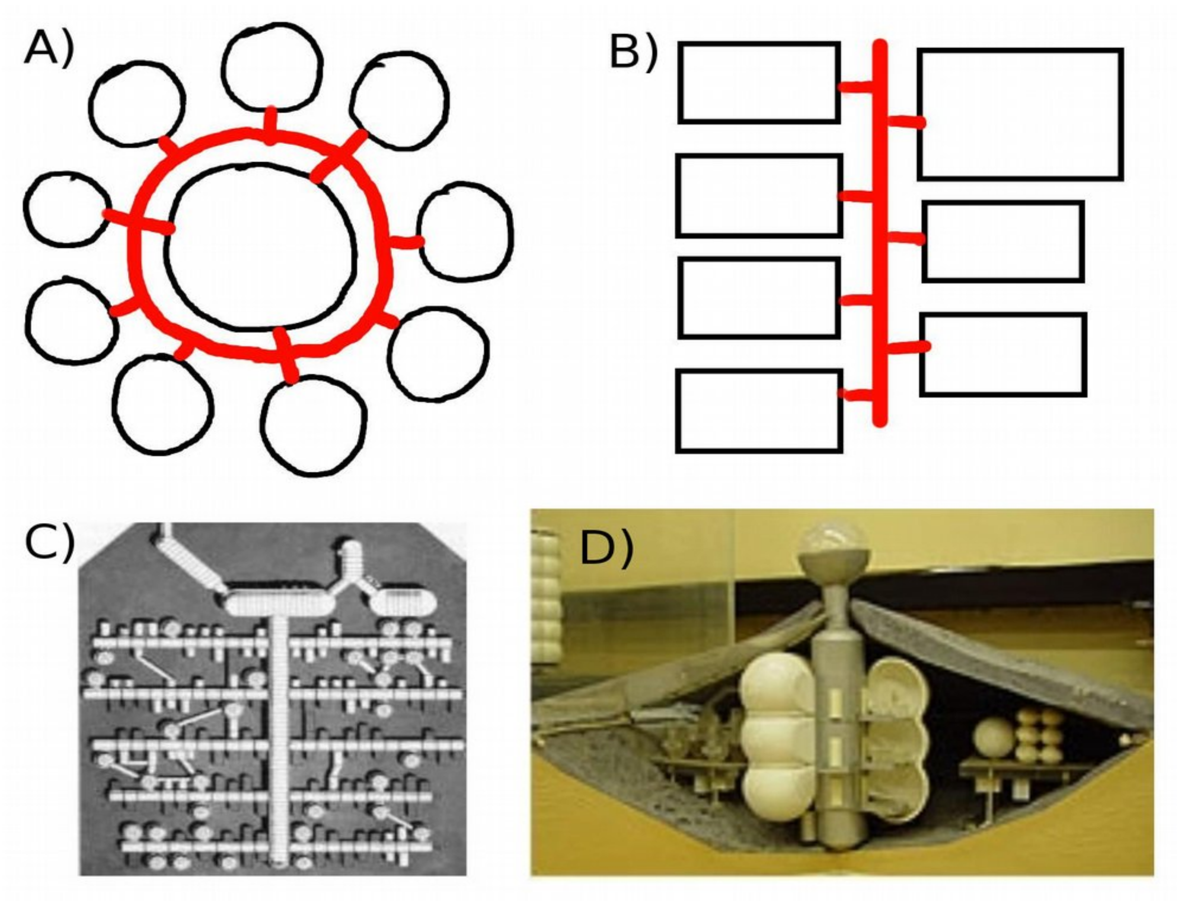
Communication routes: There could be different types of communication in a base. The most obvious is sneakernet. Walking should take less effort on Mars, as in lower gravitation conditions it is easier to start moving. However, the larger the base, the greater need for efficient communication. Any kind of mechanized transportation requires additional energy, which is valuable in Martian base. Thus, it should be recommended in exceptional conditions only. There could be listed: on-wheel transportation, water, suspended (pulley, cable car). The first Martian base is rather going to be small and would not really require on-wheel transportation. Anticipating its development and expansion, however, requires designing communication ducts to allow any changes, expansion, and introduction additional roads to be simple to make. Fast and efficient transportation makes sense only when there is no need to go through airlocks. Thus, communication routes of that kind are rather recommended for large buildings, alternatively they can be built as separate, closed constructions intersecting many modules. A net of main roads in the base will be the crucial core of evacuation routes. They should lead to: the next module, outside, and possibly to the shelter. The roads should be well-lit.

Vertical communication: This kind of communication does not play any important part in cities on Earth. Underground bases and multi-level bases should be connected with vertical communication widely available, as they are going to be as important in Martian base, as the most important horizontal communication on Earth. The most comfortable element of vertical communication is a lift. It allows fast transportation done without effort between levels, floors. An elevator, however, requires additional energy, which is valuable in Martian habitat. Alternative technical solutions could lower energy consumption needed to lift an elevator, and a dilatory system for a lift going down. Lifts occupy less space than stairs and ramps. It should be also pointed that on Mars, thanks to lower gravitation, lifting an elevator does not require as much energy as on Earth. The same effect applies to walking—a gaite will be lighter and longer, and to go up will require less energy, what allows building e.g. steeper stairs, which occupy less space.

Roads' enlargements: They may be needed for different purposes: social—to create places for social meetings, functional—in places of the highest intensity of traffic, in communication junctions etc. Enlargement of the highest importance roads will create small squares. They should function not only for communication purposes, but also recreational.

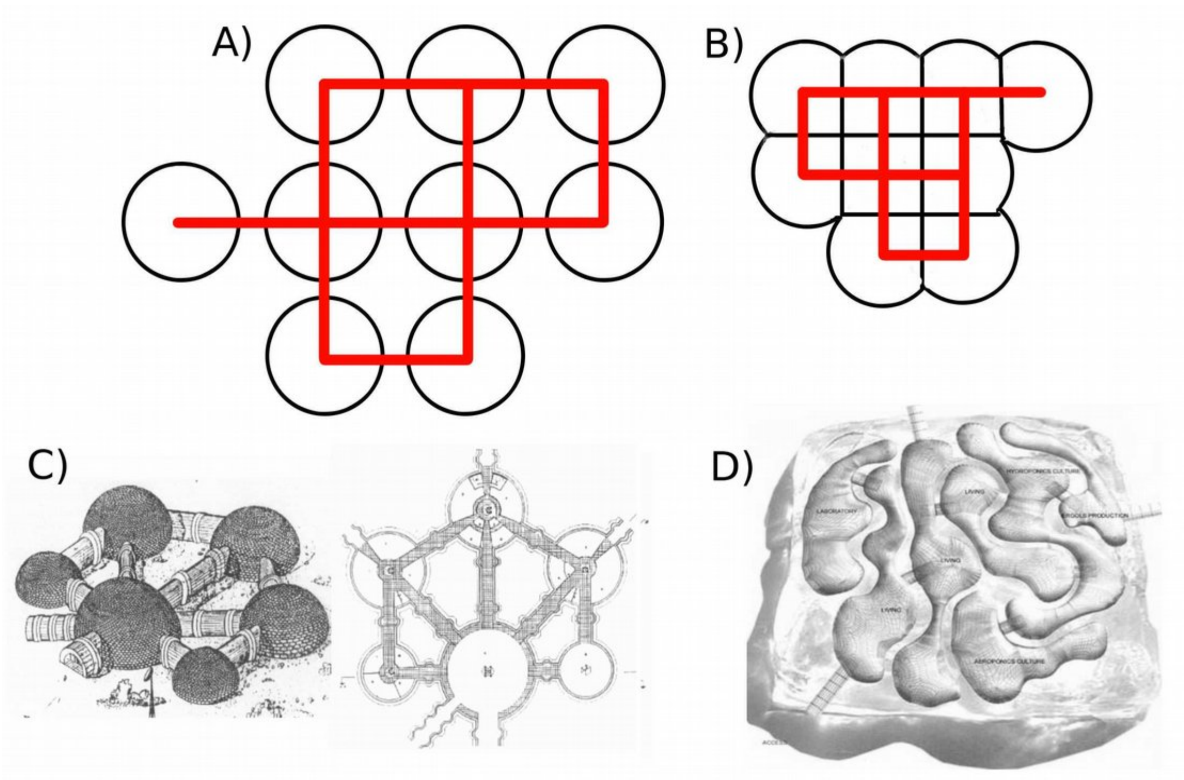
The whole net of communication in Martian base should be closed in hermetic construction. The author points three spatial solutions for communication in Martian base: outside communication, communication connecting modules and peripheral communication. Every one of those solutions has its advantages and disadvantages. Choosing one of them will depend on technological possibilities and economic foundations of the base.

Outside communication (Pict. 6.82): A communication net is planned inside an independent construction, built for communication purposes only. Living and working areas are connected to this net with airlocks, common entrances or passages. Independent communication routes allow designating routes for wheeled transportation, walking routes, moving walkways, cable-cars etc., and separating them from other functions, without any interference allowed. Due to such division fast transportation (mostly on wheels) is not introduced into living and working modules, what enhances the safety level. This way roads are clearly and straightly planned. Movement through modules planned away from each other is fast. Any redevelopment of roads is connected with changes of those constructions alone, without any influence into functions of the base. It is a very profitable solution for the base which is constructed for development and extension. Monitoring of such communication routes is easy. There are also disadvantages of such solution: a failure of such outside roads would cause shutting down all of the modules and their separation. To lower such risk the communication tunnels should be cut short to the indispensable minimum length and divided into segments. The best option would be to build two similar outside communication routes. This solution is very expensive.



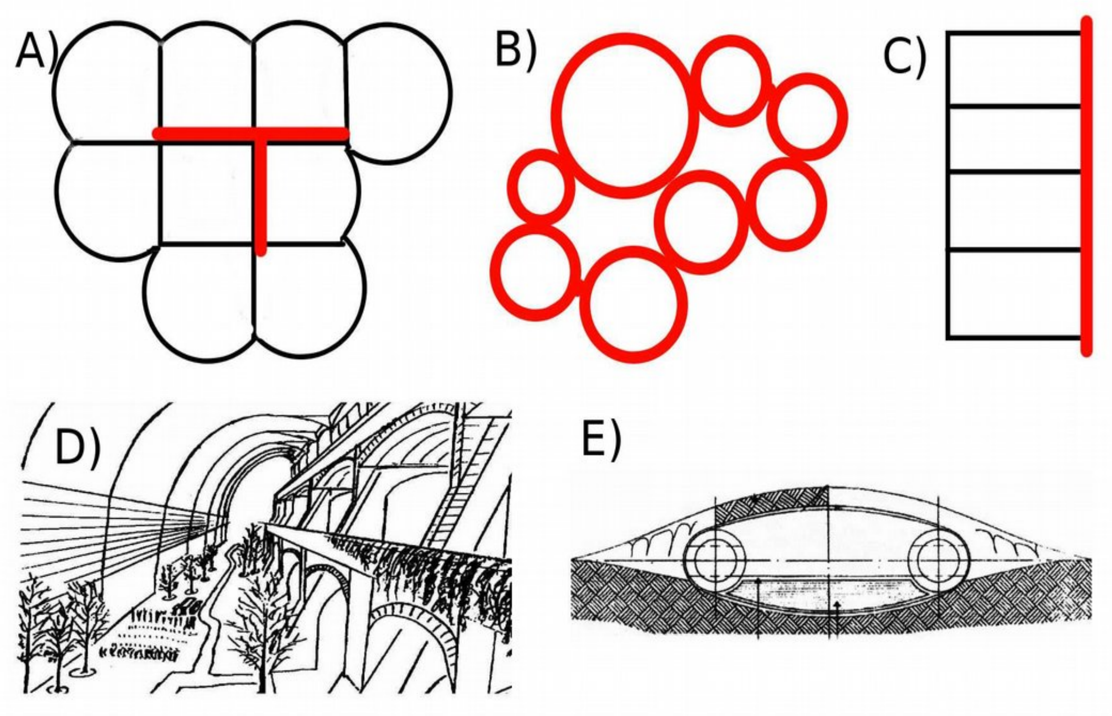
Picture 6.82: Communication (in red) outside route: A,B) cross-sections and examples: C) pneumatic city Ibiza City (Muire 1971),underground base—KBOM project (Anatoly Zak, www.russianspaceweb.com)

Communication intersecting modules (Pict. 6.82): communication routes are planned in the middle of building units. Such a solution enables to achieve open and widely available roads which collect traffic from the whole module easily. Social contacts may become easier. People would have more opportunities to meet. Every one would know their habitat better because they would be forced to cross it more often. In case of failure of a part of it—a module—fast evacuation is easier, to a safe part of habitat. The main disadvantage of this system is creation of a much longer way from point A to point B, and introducing inside modules fast-ways would cause accidents. This solution is connected with slightly more difficult monitoring and maintenance of roads. What is more, such kind of communications takes large part of the habitat.



Picture 6.83: Communication (in red) intersecting modules: A,B) cross-sections and examples: C) multi-modular base (Sabouni and others 1991), D) base in an ice-block (R&Sie 2002)

Peripheral communication (Pict. 6.84): roads are planned on the perimeter of modules. This way the main communication routes are not introduced inside modules, and interfere less into their area. They may be built as a part of of the insides or as separate oblong building. The length of the widest collective roads is cut shorter then, and fast ways cannot be a serious danger. As for the social side of this solution, people can cross different modules and get to know them, however, those who are in the hurry or have their reasons not to go inside, do not need to. Peripheral communications should be well-thought to create comfortable moving around traffic between its sections (especially troublesome when on circle perimeter) and to lower any danger in case of failure of one of communication sections. There could be added e.g. an inflatable corridor for such cases.



Picture 6.84: Peripheral communication (in red): A,B,C) cross-sections and examples: D) brick base (MacKenzie), E) inflatable base (Chow and Lee)

Conclusions for architect

There is no possibility to list all of possible rooms that will be needed for Martian base right now. There should be planned some for sure such functions as: living, working, recreational, and technological.

1. There should be taken into consideration private cabins, bathrooms, kitchens and messes in the section for living function. They should be built (small or large) according to the needs of habitants, depending on the length of time they will spend in Martian base. In case of small number of habitants there should be kitchens connected with messes, and in case of large number of habitants there, it could be reasonable to plan places for collective feeding. The number of bathrooms and their availability will be dictated by the number of habitants and management of available area. Due to economic limitations there should be Jack and Jill bathrooms for at least several people (as it is e.g. in student dorms).
2. There should be considered, in the functional plan of base, different recreation facilities, because the more kinds of entertainment and recreation, the better psychical comfort of habitants (Evans and others 1988). A well equipped gym is a crucial element of recreational function.
3. Recreational function should be well developed. It cannot be closed inside planned for the purpose rooms alone, but there should be public places designed for this function in different places of Martian base. They will

enhance free social interactions, they will function as free meeting places and allow people for a short stop during the way to work, look outside the window, wait for somebody.

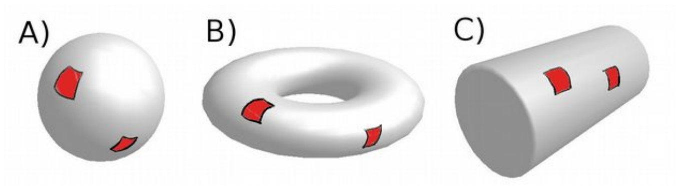
4. Optimal functional plan should be the base for designing Martian base. However, flexible space is crucial. The more freedom is to shape the base, the more open for purposes and ideas of habitants will it be.
5. There should be taken into consideration that some places will function for several purposes at the same time, e.g.: a greenhouse is a technological room —BIO LSS, working place, and green recreation place; private cabin is a house, a recreating room (a good place to meet with friends, play, read books etc.), and in some cases also a working room[15].
6. Some of the function will require unqualified protection against dangerous radiation (e.g. a shelter, technical rooms with sensitive equipment), others—different coatings, e.g a shelter built deep under the ground, and a greenhouse under a transparent roof.
7. Separation of complete different functions is crucial, e.g. noisy from silent, well-lit from dark, working from recreational, public from private.
8. The functional design should support and regulate the daily schedule.
9. The main communication roads should be decided in advance. It should be clear and simple to enable moving from point A to point B in the most efficient way. The main communication routes will be at the same time evacuation routes, thus, they should be shorter, wider, and collect effectively traffic from minor roads.
10. There should be designed in advance exits to surface. There should be airlocks adjacent to airlocks, changing rooms, and rooms to prepare people to go outside, leave luggage (e.g. ground samples) and its temporary keeping, some place for a cart etc.
11. The communication net depends mainly on the size and shape of building units, and on their connections. Communication routes may be designed more freely in larger space, than in case of base built from small modules, especially when the entrances are firmly planned.
12. Functions should be planned in Martian base to allow better exposure and visual contact with biosphere and/or surroundings, to enhance psychical comfort of habitants.

15 Scientists were eager to work in their private cabins in their free time on polar stations (Evans and others 1988)

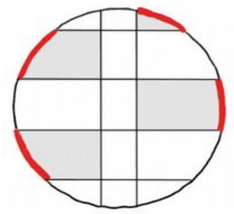
6.4 Interiors

6.4.1 Interiors and constructions of base

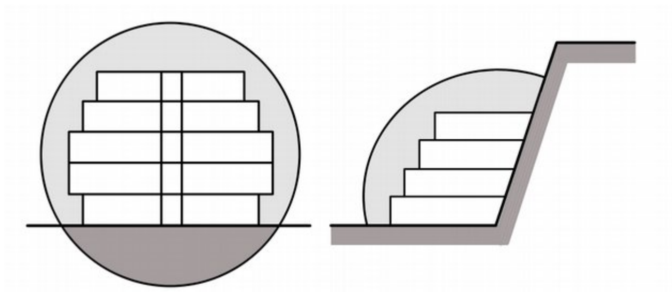
Traditional rooms on Earth are cuboid. This form is a consequence of easiness and low building costs of creating such forms (usually chosen in different building technologies). The interiors built in such a shape are easy to arrange with furniture available in shops. Cuboid form is the simplest form of a room, which is built on Earth. When trying to imagine a room, it is usually a cuboid.



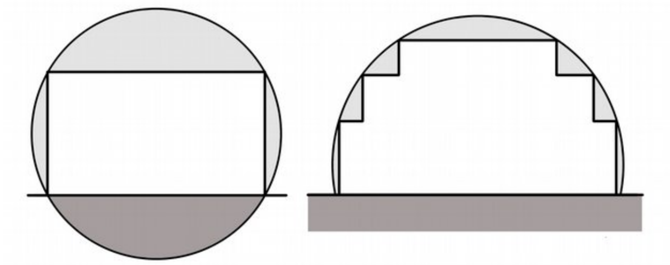
Picture 6.85: Curves of A) sphere, B) torus, and C) cylinder



Picture 6.86: Curves on different floors



Picture 6.87:Case A—separation from curves

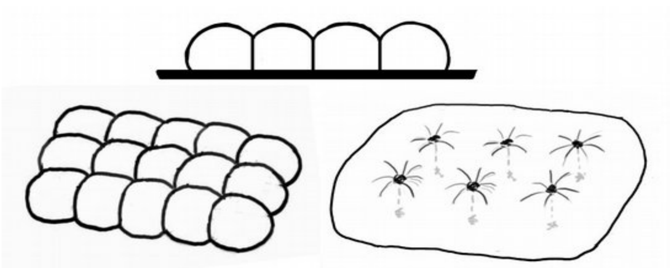


Picture 6.88: Case B—'straightening' curves

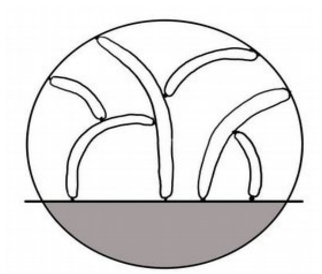
The form of Martian base will be oblong. This oblong shape influence very strongly the way of arrangement of interiors. The curves of outside walls of base seem to be a problem, as it is difficult to arrange there traditional elements of furniture. The form of Martian base will be probably based on sphere, torus or cylinder. Every type of those form has a different type of curves, which should be taken into consideration while planning the arrangement of habitat space (Pict. 6.85). The easiest one is cylinder, as the curves are steady in line. In case of sphere and torus the curves go in two ways. When base has many floors, there are different curves on each floor (Pict. 6.86). Planning elements for such interiors to fit any place in there is very difficult due to those different curves. That is why **curves are the main problem for space arrangement of the interiors of Martian base**. The author thinks that problem may be solved in four different ways. The first solution is separating base form curves completely by building the whole construction under the outside coating—case A (Pict. 6.87). The second solution is that curves may be 'straighten' with introducing some elements, or whole planes, to create insides frames for habitable areas—case B (Pict. 6.88). The third solution is 'losing' curves, lowering to minimum area of divisions that consist curves, creating tightly adjacent oblong forms or introducing tightening and flattening the structure elements—case C (Pict. 6.89). At last, the fourth solution is to use the curves to arrange interesting and original interiors with the use of non-standard elements—case D (Pict. 6.90). Every solution has its advantages and disadvantages.

In case A (Pict. 6.97) due to complete separation from curves there may be planned more traditional interiors. It enables the use of standard fitting elements to arrange rooms, which is not possible with curve divisions. However, the more floors, the more space is lost for the sake of such separation from curves. It is not a profitable solution, as more finances should be planned to build e.g. balconies or communication routes. However, free space crated there could be dedicated for growing plants or filled with anti-radiation materials.

There are similar problems of losing habitable area in cases B (Pict. 6.88) and A. Economically unprofitable element adds to that, as tightening floor and ceiling elements are additional here, only to 'straighten' curves. Such divisions do not need to reinforce anything, however, they can be connected with the interior construction only. Due to that, they may be cheap and easy to install. Straightening elements may be considered in this solution as parts of the construction connected with the outside cover, e.g. in form of inflatable structures. Lost space may be used practically, which is a better justification for case B: it can create a good separation from outside cover. There could be hidden aesthetically in those places technological infrastructure (cables, pipes). Moreover, such space may be filled with insulation materials. In case B there is a double wall, which complicates outside windows and doors construction.



Picture 6.89: Case C—'losing' curves



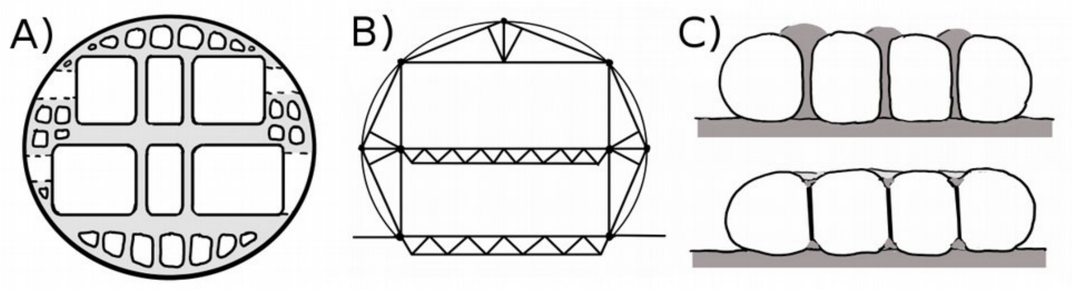
Picture 6.90: Case D—interaction with curves

In case C (Pict. 6.89) there are still some curves to deal with. Thus, the problem stays the same, however, it affects much less of the space arrangement. Where there are only several curves there might be left some space without any accessories, or firmly fixed divisions may be installed in those places. When modules in a shape of dome are tightly adjacent to each other, the division walls straighten.

There is less habitable space, but there is no need for additional elements to fill in or additional construction elements. The walls created in such way are smaller and flat, so it seems that building them should be cheaper and easier. A similar effect is achieved when in the inside of a dome there are tightening studs installed. However, it should be taken into consideration that case C is connected with much space for windows lost. However, it is profitable to deplete the surface of the outside cover which should be protected from the outside environment. Case C is suggested for large oblong structures, where there are no many floors, and for multi-modular bases.

In case D (Pict. 6.90) the elements to arrange rooms should be designed to fit freely a non-standard oblong cubature. Their installation and choice probably requires a completely new procedures. There will be created completely new interiors, where creating homely atmosphere is difficult. Such original style, however, may build identity of completely new and exceptional place—of Martian base. It is the only solution which uses the whole habitable area under the outside cover of the base. There could be planned spacious rooms, and windows are not going to be extended in any way there.

The construction of the base should be oblong. This solution bears its consequences, especially in case of scale of the interiors. Architect has to decide at the beginning what to do with curves. It has to be done to avoid the problem of restricting flexibility of the insides by the division for arrangement of the interiors, which fit flat divisions only, or specific curves, different on each floor (Pict. 6.86). Such temporary solutions would point to lack of capability in the subject of Martian base architecture. Curves are a problem which leads to e.g. the need of building additional divisions, as in case B, or building inside additional reinforcing construction, as in case A. Due to economic and financial matters, there should be found simple solutions of the problem at the stage of thinking about the construction and architecture of the base. **The plan of interiors may influence significantly the construction of the base**. Depending on the chosen technology, the general outside structure may be connected differently with the anticipated interior structure (cases B and C). In case of building a habitat from SM materials, it would be reasonable to shape a module in a way to build outside and inside walls as one unit, and space between the walls could be designed to reinforce the construction (Pict. 6.91 A). Such solution helps to support the reinforcement construction and allows people to work faster, because the installation of the inside and outside construction is done at the same time. There could be also expandable construction planned in such a way as the inside construction would create a scaffolding for flat walls and connect with the trussing of the outside coating (Pict. 6.91 B). Such construction as a unit would be really firm. Similar discussion could take place in case of other types of expandable constructions. Different constructions require separate additional divisions. It is important then to anticipate points of connecting for those additional element in the construction. Case C may require introducing interior, base construction's reinforcing elements: poles or ropes (Pict. 6.91 C).



Picture 6.91: Examples of bases with outside and inside construction united, with elimination of curves inside: A) construction made from Shape Memory materials, B) expandable construction, C) pneumatic construction with poles or walls inside.

6.4.2 Elements of interior design

Specification of elements inside Martian base

There are many different elements, which may create interiors in Martian base. Most of them are the same elements that are known form the interiors in buildings on Earth. There may be greater or smaller need for some of those elements due to specific of Space missions. There could be also a huge difference between the details of the interiors on Earth from their counterparts on Mars. It is mainly influenced by the restrictions in the bulk and volume of things that may be delivered from Earth. The members of Martian missions will not be allowed to take their all clothes, souvenirs, books. They will be given permission to take some sets of their clothes, e-inks with books, some personal belongings as eyeglasses, toothbrushes. Those things will not occupy much space, that is why in their private cabins they would not require many pieces of furniture to keep those things. To keep souvenirs there will be needed a piece of place to pin photos, etc. Thus, limitations of bulk and volume of transported things from Earth influence in many points the architecture of Martian base. To plan it appropriately there should be no element omitted, directly and indirectly influencing the construction.

Besides well-known in every-day life and work interior elements, Martian base interiors should be equipped with other objects. The list should start with all kinds of supporting elements, needed in conditions of lower gravitation, to move around smoothly and to keep balance. Those are different kinds of handles, railings etc. There were any of such supporting on first Space stations and it took a very short time to realize that they are crucial in micro-gravitation conditions. There are standard in today's Space architecture. Their structure and fastening is standardized by NASA MSIS-3000. It is not known how people will behave in 1/3 g, but it maybe anticipated that at least at the beginning of the mission they will have problems with moving around in such new conditions. The evidence to prove it is visible in lack of coordination in the movement of the first Moon astronauts. However, on Mars there is twice as larger gravitation than on the Moon, but at the same time it is three times lower than on Earth. During the long stay on Mars people will probably adapt to those different conditions, but supporting seems crucial for every new crew coming to the Red Planet. Due to lower gravitation ergonomic shape and size of elements will probably be different from those on Earth. Any detailed specifications will be listed on the base of simulations.

Many interior design elements will probably look different in Martian conditions. They will differ from they counterparts on Earth on the basis of technology and material used to produce them. Wooden furniture and doors, specific for Earth's households, are not economic solution for Mars. Their weight is too large, and producing them from local resources is impossible, because there are no trees on the Red Planet. Outside doors leading to airlocks are especially different, as they must be airtight and able to endure large differences in pressure. To assure enough doors in the base they should be made with the use of innovative technologies based on light expandable materials. The joining details to install them, and the system of closing, securing them requires specific plans. **Traditional Earth's interior design elements are not adequate to arrange Martian base interiors**. Homely atmosphere and the specific climate of Earth's interiors may be achieved with linings in different colors, patterns, transparency of materials, and also with pictures, photographies of the views and nature, landscapes. To design interiors for Martian base the analyses from different points of view are crucial.

Classification of interior design elements

Interior design elements in Martian base may be divided due to different criteria. The author here decided to divided them according to four types of criteria.

Considering elements' assignation durability to a specific place in such base, they may be divided into:

a) fixed: They are elements of the interior fixed firmly to one place. They create some fixed frames for the scenes arranged in different places of a base. On the one hand, they limit flexibility of a room, on the other hand, they give to the place a kind of a substantial characteristic structure, which builds the identity of such place, and this is an advantage. Such leitmotif will be always intuitively recognized, regardless any introduced arrangements. Of course, such fixed elements should be planned for places which are going to be arranged once and for ever due to their specific purposes: monitoring rooms, laboratories, bathrooms etc. Fixed divisions are easier to treat them with acoustic isolation.

b) flexible: They are elements of the interior which can be arranged freely. Such objects may be temporary fixed in one place (e.g. a sliding wall), or placed freely and movable (e.g. a chair). Their function is crucial for every-day life, especially in artificial environment. Thanks to those elements interiors become vibrant and they can break the monotony caused by staying in the same place for a long time. Those elements should be light, easy to fix and disconnect, move to other place, connect with each other etc.

Elements of interior design may be divided due to their place of origin:

a) from local resources: They may be really different elements, depending on sophisticated technologies introduced on Mars. The first resources to use will be those widely available, requiring the lowest processing level, so they should be rocks and ground. There may be some stone-masonry elements built: walls, studs, arcades, balustrades, fences, stairs, landings etc. There is artificial atmosphere inside the base, so the use of wet binding materials is not a problem there. Some scientists persuade that there is possible to process on Mars many different building materials, such as: plastic, glass, aerogel, metal, steel (Noever i in. 1998), plaster, concrete (Zubrin i Wagner 1997); and also that it should be possible to grow bamboo, straw, wicker and fiber to make fabrics. Processing those materials requires more sophisticated technologies, but it is still possible that some of them would be introduced in early stages during building the base. Processing of plastics seems especially promising there. Polyethylene (the easiest material to produce plastic) may be used to make many different materials: foils, simple domestic appliances, pieces of light furniture etc. Variety of produced things seems to be almost unlimited if 3D printer will be delivered to Mars, the type: RepRap (2007). It is an easy tool, which may be programmed to make many different things, its own replica including. RepRap may use plastic, ceramic and metal to make things. First of all, plastic allows diversity, and metal may be used to make durable elements.

b) transported from Earth: They may be made from different materials and be of high quality. They should be, however, light and easy to pack, to transport as many as possible of them in one rocket.

Interior design elements may be divided according to their function into:

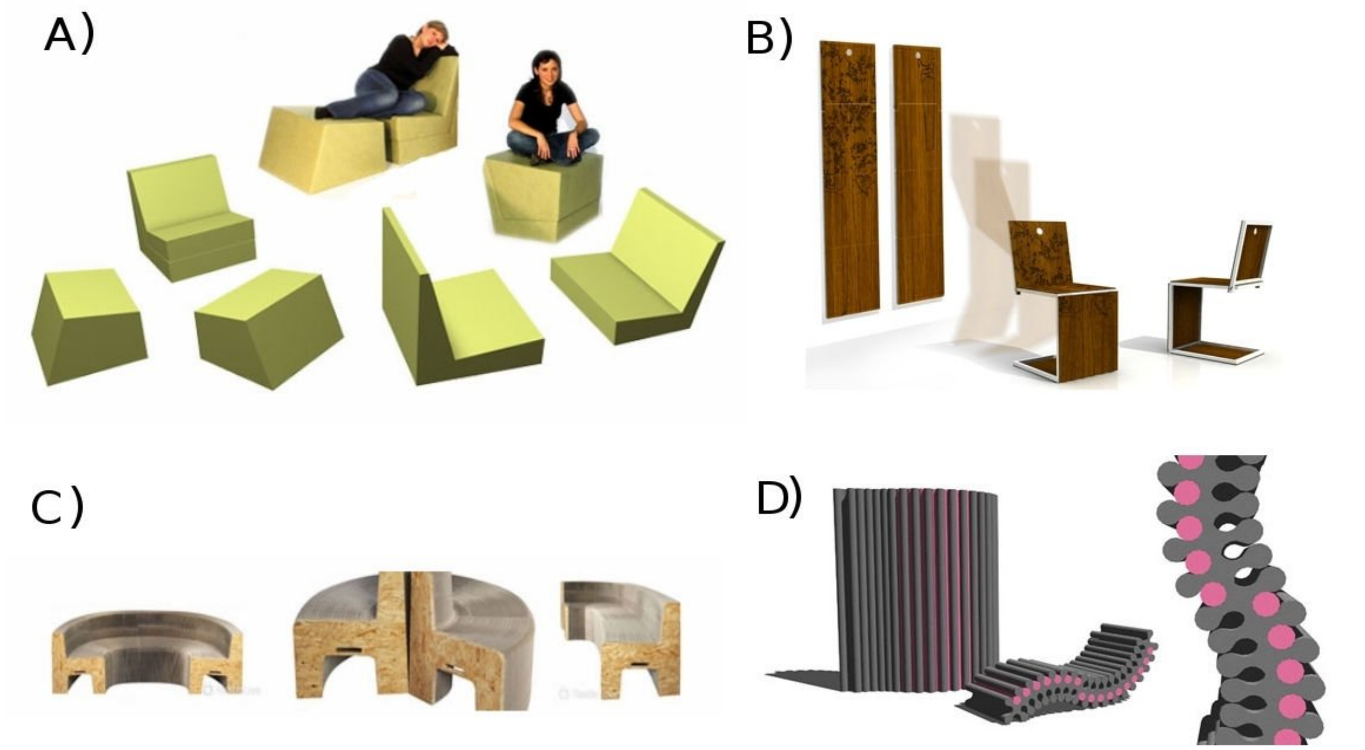
a) precise elements: They are elements designed for specific functions to optimize their performance for the specific task they are made for, e.g.: laboratories and bathroom furniture etc. They are made for one specific function, and their quality is very high.

b) universal: Multi-functional, versatile elements to perform many tasks. They are not designed for one specific function, thus their quality may not be impressively high while performing in various tasks.

Interior design elements may be divided according to the number of their components into:

a) one-component elements: They are mostly sophisticated elements, precise elements. They have to be one complete unit to perform properly, e.g.: a comfortable armchair, a shower etc. Damaged elements would probably need to be replaced with a new sophisticated one, even if the damaged element is a small part of it, because transporting spare parts for those one-component elements would be too expensive and not economical.

b) multi-component elements: They are elements built from many identical elements, or at most from several types of elements. They are built from modular components connected differently. Variety of configurations allows making elements of the same type, but looking differently, or elements performing different tasks because of different combinations of connections.



Picture 6.92: Flexible furniture: A) furniture 68cubic by Nadine Milz, B) Pick Chair by Dror Benshetrit, C) FlexibleLove by Chishen Chiu, D) foam furniture by Carl Fredrik Svenstedt

Martian base should be equipped with some precise elements. They are mainly specialist elements—for laboratory, for the base maintenance, for kitchen and bathroom. The rest of the elements, which optimization is not their critical factor, may be universal. Those objects, designed properly, may be single-functional and multi-functional. The versatility of universal elements gives opportunity of infinite number of methodologies to their exploitation and assemblage. It is a great advantage and anybody can rearrange those elements according to their needs, that can be changed in time; to transform their surroundings; to discover new elements which variability of exploitation is yet not known, and which may become useful in Martian base later. The need to introduce changes may apply to changing the arrangement of some elements to adjust them better to the way people move in 1/3 g conditions. It is also important that universal elements may be operated safely by anybody. Many ways of rearranging universal elements in spatial forms benefits in breaking the monotony of limited environment in Martian base. It is an economical solution. It is easier to make an easy universal element, which may be easily replaced with a new one in case of damage of such element. Those are the reasons why the author here suggests the usage of universal elements to create the interior design in Martian base.

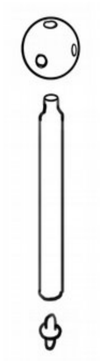
Interiors of Martian base should be open for the needs of the habitants, and they should be also flexible to escape monotony. Architect may achieve such effect by introducing universal elements. Those elements should be flexible too. They may be of two types: consisting of modules connected in different ways—multi-element (Pict. 6.92 A), or of alternating size—expandable (unfolding, stretchable) (Pict. 9.92 B,C,D). Flexible elements consisting of modular elements are preferred here, because they give the widest range of possibilities. Modules—repeatable elements—are simple constructions, but arranged in different ways create original and unique forms. The use of one or more modular elements to build multi-modular objects allows achieving unique elements, as it is when a child plays with blocks. In case of damage modules can be easily replaced and the loss of some is not such a nuisance, as it is in case of precise elements. Additionally, modular elements should have a replaceable lining to change their color, texture, transparency. Connecting modules should be fast and simple. Joints should be placed in such a way as to allow arranging modules on many sides. The way of putting elements together should be designed to create sound and stable elements. The joints, connections should be designed to allow arranging elements freely in a room. There may be the case of balancing elements or fixing them to firm elements (walls, floors, ceilings). In the first case balancing should be taken into consideration as an additional stage of putting the elements together. The easiest way is to balance elements with bags filled with ground. In the second case, the firm divisions should be ready with some elements, joints, to fix flexible elements.

Shape and size of modular elements should be taken into serious consideration to create functional and multi-functional elements of interior design. To make a division wall as well as a chair from a given module, it has to be of a size adequate to make a comfortable seat, and a wall that will fit the height between floor and ceiling. That is why modules should be ergonomic and of a size that fits the size of rooms in Martian base; it could be other way around: the height of insides should be adapted to the size of multiple modules. The easier is the shape of modules, the easier is their usage in different cases. However, more sophisticated shape may open the way to achieve more interesting elements. Some examples of flexible elements are shown in the Pict. 6.92.

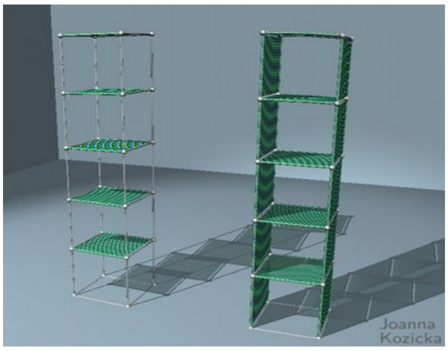
Modularity can become monotonous only when modules are too large and easy to recognize. Thus, small modules are better. They allow creating more complexed and original elements of interior design. On the other hand, too small modules may be awkward for making connections.

Flexibility seems crucial for the comfort of habitants, however, some firmly fixed elements are required too and should be planned. They create stable general frames of a room. Variety created by flexibility is needed to break the monotony; stability enables places to keep their identity, recognizability. That way there are created well known places in the area, which can change, evolve. Such stability is needed for orientation and to keep the sense of security in a base, despite of introduced changes. Planning fixed elements is justified only when their look and place inside are unique for every room.

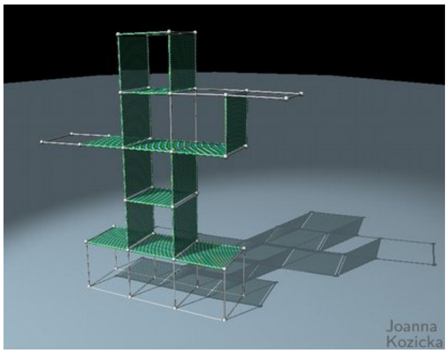
Due to economic reasons there should not be anticipated elements solely decorating. However, considering socio-psychological problems, this unique function should not be ignored completely. To create attractive interior design, aesthetic value should be also introduced into practical, functional elements. Modular elements, which are not used temporary as components, may become decorative elements.



Picture 6.93: Example I: modular elements



Picture 6.94: Example I: simple shelf



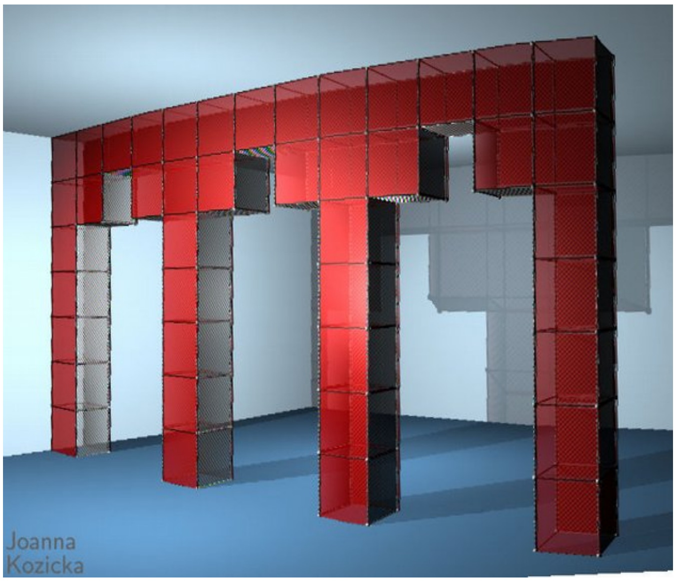
Picture 6.95: Example I: original shelf

Examples

The author shows here her four suggestions as to the usage of different modular elements designed on the basis of the above recommendations. The visualizations show variety of possibilities of exploitation to plan functional and interesting interiors.

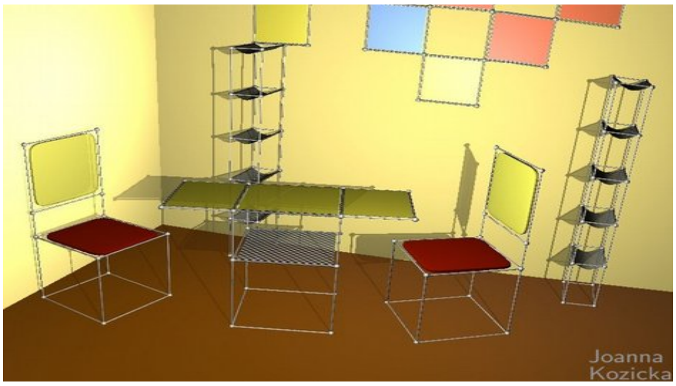
EXAMPLE I:

There are designed three small modular elements to create rectangular figures and blocks. They are: metal or plastic tube (e.g. 14 cm long), narrowing on one end into a cotter-pin; a ball with six symmetrically positioned holes to introduce cotter-pins, and a small cotter-pin on the ball to connect it with a tube on the other side (Pict. 6.93). The basic universal element is cube. Such a block, made from 3 tubes on one side, creates ergonomic stool (height 40-something cm)--when a lining applied on the upper side, or a basket—when a lining applied on five sides: the bottom one and on the flanks. After connecting a rectangle backrest to such a stool, a chair is created. An upholstery may be made from tubes beaded into replaceable nets or fabrics of different colors. They may be two-sided, zipped or buttoned, with a pocket for a cushion to create a comfortable backrest and seat.



Picture 6.96: Example I: arcades

Picture 6.97: Example I: small shelves

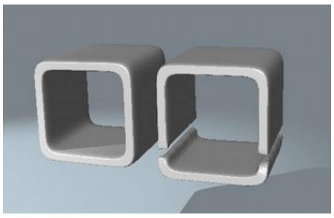


Picture 6.98: Example I: a table for two

Picture 6.99: Example I: a fragment of a dining-room

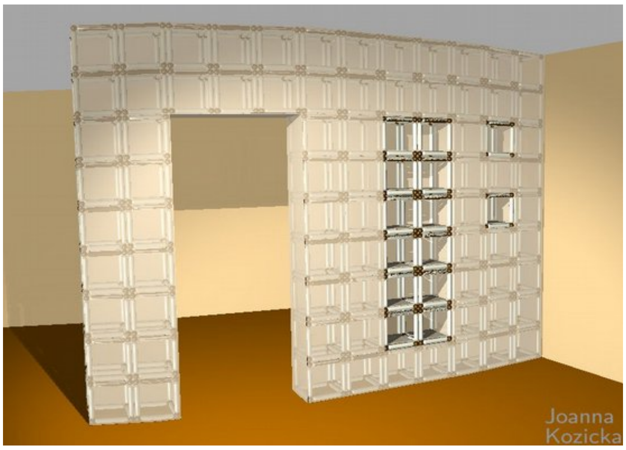
Successively put one on another blocks create a pillar. It may be a simple pillar—in a form of a truss. It may serve as a holding to hang different things (a towel, a lab's gown) and helps to move around in lower gravitation conditions, because it may be grasped on different levels. Lamps could be comfortably attached to such a pillar. More decorative pillar could be achieved by applying colorful linings onto one. When a lining is applied horizontally, there are shelves made. When the sides are left without a lining, shelves are available from many sides. Shelves may be covered on different sides—on one, two or three sides. Thanks to modular tube element and cotter-pins going between, shelves may be of different (easy to change) depth, they also may be two, three, or four-sided. They may be regular (Pict. 6.94) or more complicated, original (Pict. 6.95). Such blocks are useful to build walls: complete or openwork wall units, or some even more sophisticated in form (e.g. arcades-Pict. 6.96). The insides of walls may be filled to improve their acoustic isolation, to ballast and make them more rigid. If there is anticipated a possibility to attach those tubes in floors and ceilings, there could be made poles, stubs to fit the height of a room. By applying the lining onto them, a screen is created, a railing, or a thin division wall. They could be also hanged on strings on the shelves, made from tubes and linings (Pict. 6.97).

The suggested modular elements may be used to make all simple elements of interior design: division walls, furniture for sitting, tables, furniture to store things, decorative elements. Pictures 6.98 and 6.99 show the insides of a dining-room created solely from described here modular elements.



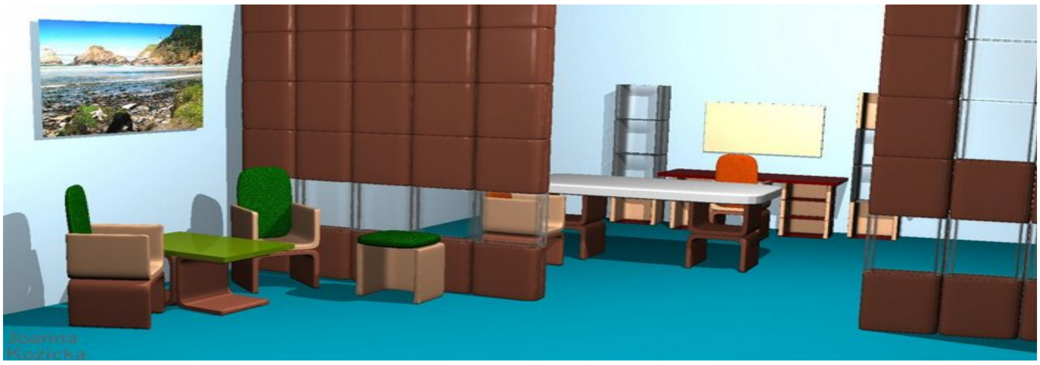
Picture 6.100: Example II: trough-like profiles made from SMP

Most of interior designed elements built that way need spatial construction to be firm (flat forms are not so stable). That is why instead of blocks built from tubes, balls and cotter-pins there might be used one-element cubes, in expandable or pneumatic unbending construction. Such modules should be connected differently with each other (e.g. with press studs, clips, magnets or other). An example of a wall made from such elements shows Pict. 6.101. There is installed a doorway in it, and shelves. The rest is covered with a thin lining.



Picture 6.101: A wall unit made from pneumatic unbending elements

Picture 6.102: Example II: ER room



Picture 6.103: Example II: ER chamber: waiting-room and surgery in the background

EXAMPLE II:

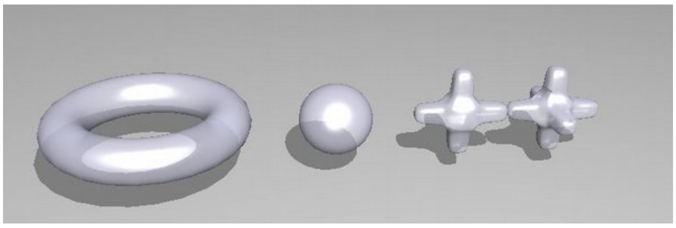
There are designed two modular elements, possible to connect them into a third basic element. It is a profile, its walls several centimeters thick, square in shape, with curved corners. It is divided into two unequal troughs—one deeper, one shallow (Pict. 6.100). Suggested dimensions for such a two-element profile are about 50 cm x 50 cm x 50 cm. One of the profiles could be about 30 cm high, the second one—20 cm. Elements are made from SMP to be packed tightly during transportation. There are suggested foam profiles, transparent, and composites (reinforced with fibers). There would possible to paint them, to insert them into upholstery pockets, to glue or clip a lining onto them. If they should be processed *in situ*, they could be ceramic.

Suggested elements may be used to built a comfortable stool or armchair. Such element could be also taken apart into two equal parts—25 cm high, to make ergonomic table (3x25 cm = 75 cm—the height of legs of a table). Profiles may be connected in different configurations to make seats, supporting for working tops and beds, shelves, bookshelves, division walls. There might be suggested several types of connections: cotter-pin, screw, gluing. On the profiles there could be attached wheels to built movable armchairs, trolleys, carts, and other kinds of household useful pieces of furniture.

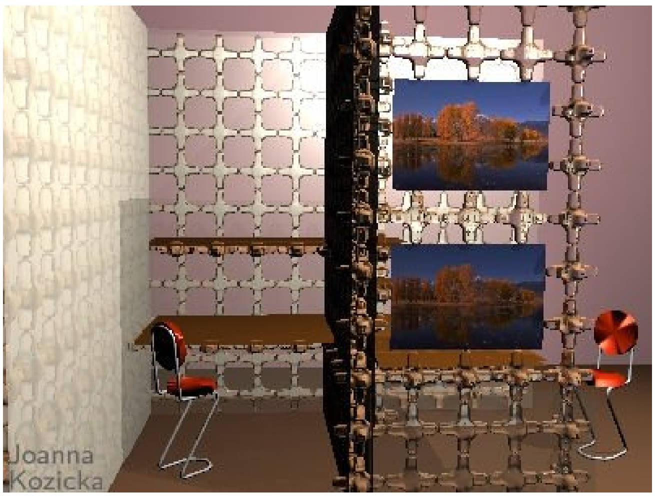
Pictures 6.102 and 6.103 show the author's suggestion how to plan a ER room.. The walls divide the room into a surgery and waiting room. The walls are built from shallow trough profiles fixed together. Pieces of walls are built from transparent troughs. Put into a shape of window they can give a view from into the surgery from the hall, when the doorway is blocked with a curtain. There are two armchairs, a stool and a coffee-table in the waiting-room. In the surgery, made from the same modular elements, similar armchairs are built, legs of a desk and bed, shelves to put medicines and medical equipment on, hanging shelves. There might be almost anything made from such profiles. Additional are tops (a table, a bed), a mattress (a bed), a backrest (armchair) and seats with a cushion (a stool).

EXAMPLE III:

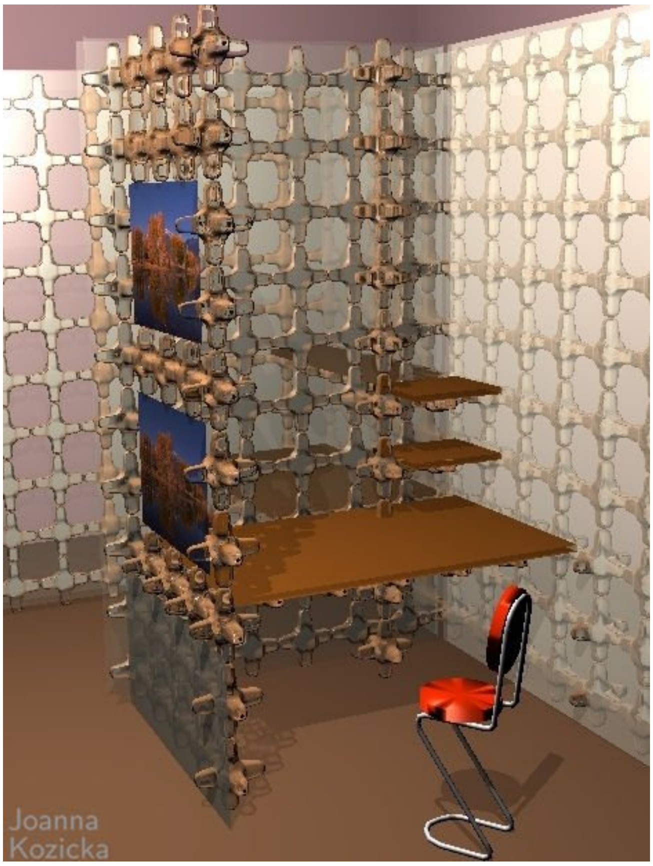
This example suggests to shape interiors with the help of pneumatic elements in form of : a ball, a torus and a cross (Pict. 6.104). They might be glued or buttoned together. In the second case there should be planned many buttons—for a ball e.g. in six places; for a torus-in four places: on a side, at the top and bottom; for a cross on four ends (when it is a four-armed element) or on six ends (when a six-armed element). It would be profitable to plan torus and ball in two sizes, to enhance their exploitation while building objects from those elements, and to diversify them. The best inflexibility would posses objects built from torus. In case of walls and pillars made from balls and crosses there should be anticipated possibility to button them to ceilings, walls and floors. Oblong panels with buttons may be screwed to firm divisions in planned places. Such walls are soft and a little flexible. It should not be a disadvantage on Mars, on the contrary, it could be a helpful factor. When there are problems with moving in 1/3 g such elements should not be a cause of any harm in case of falling. To make such divisions a better acoustic isolator, there should be a lining applied on both sides (noise absorbing) and the insides filled with isolators (e.g. nanogel pellets). There could be used a transparent and colored (in the color of pellets) lining to decorate such divisions.



Picture 6.104: Example III: modular blocks



Picture 6.105: Example III: working room created from cross-elements, view I



Picture 6.106: Example III: working room created from cross-elements, view II

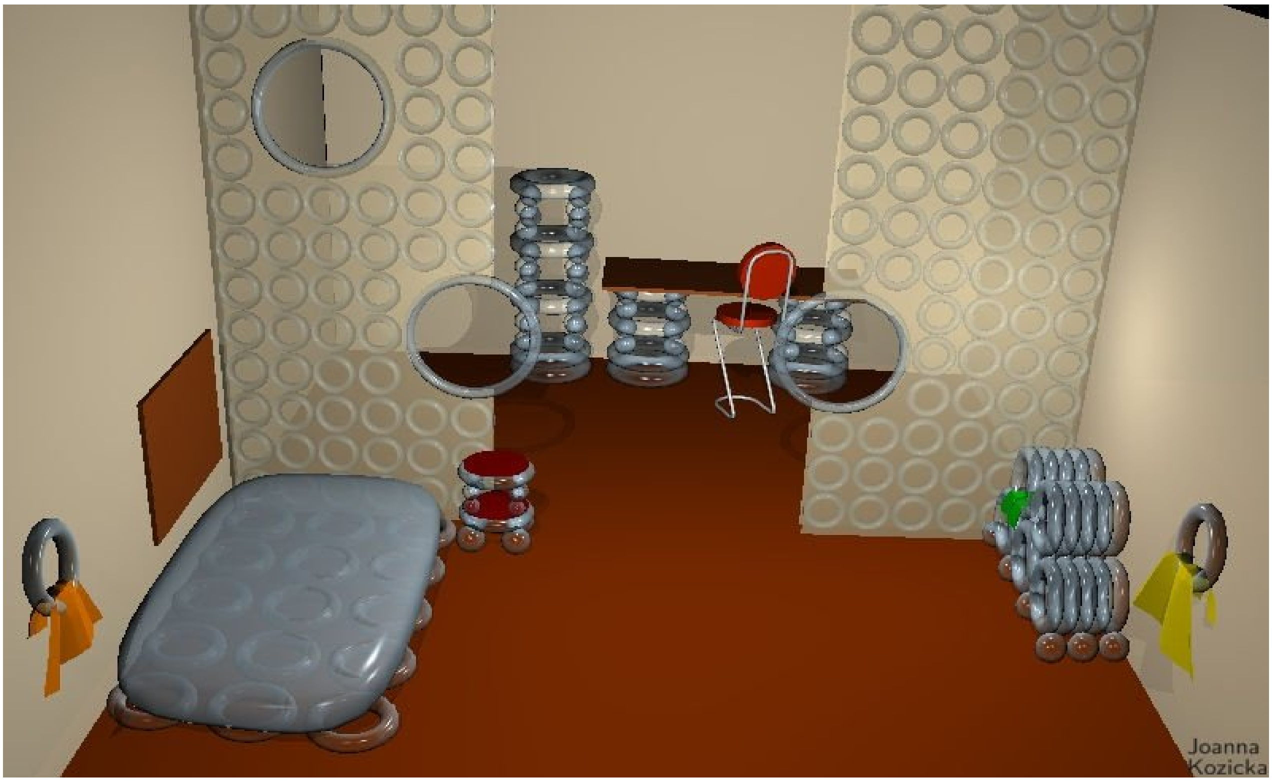
Pictures 6.105 and 6.106 show the insides shaped with pneumatic cross-elements. Four-armed crosses forme flat panels, and in places of right angle connections there are used connecting six-armed cross-elements. There are additional elements, such as firm tops for the desks and shelves, and one-element units as armchairs.

In the Picture 6.107 there is shown a suggestion for the interior design of a dining-room or recreation room (e.g. to play games). There are stools, tables, pillars, shelves and baskets—all those things are made from pneumatic balls (one size) and torus (three sizes). There are: fabric linings, cushions and firm panels to make shelves, tops and seats. There are shown in the Picture 6.108 examples of arrangement of a private cabin. As it is visible, almost all of the elements for interior design may be created from spherical and torus elements, and additionally they may be decorated as well: division walls, tables, shelves, racks, cabinets, legs for a mattress.

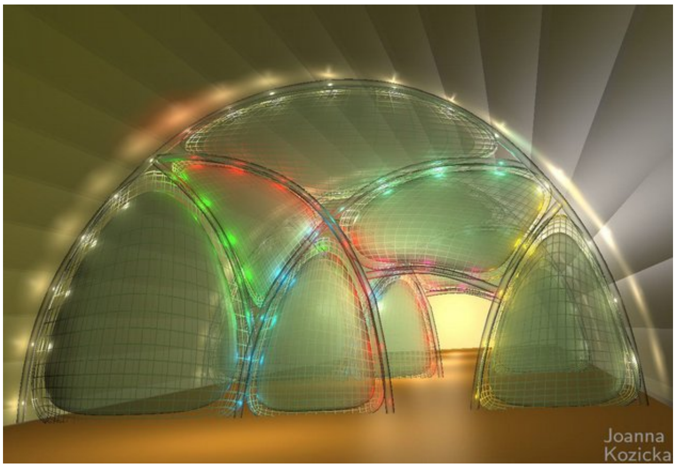
Picture 6.107: Example III: the insides of a dining-room or recreation room

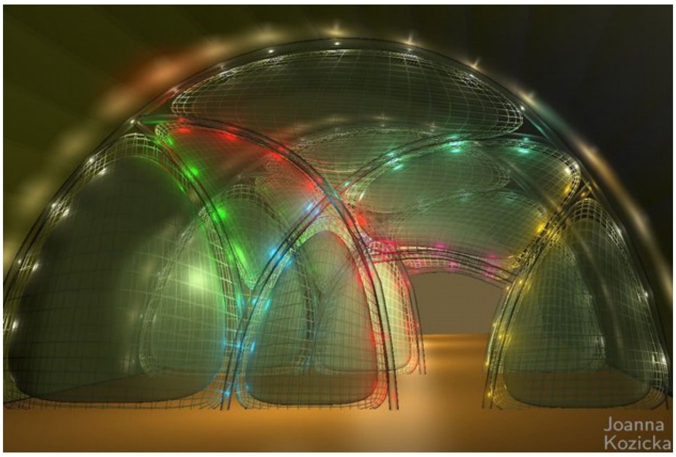
EXAMPLE IV:

There are flexible tubes here as modular elements, in several sizes, and stretchable filling. Tubular modules are pneumatic, in the best option—rigidifying after fixing them in a given configuration. The modules may be filled pneumatically, inserted into a net (also stretchable) fixed to tubular elements or to SMP elements. Flexible linings could be used to cap the construction elements, fixed at both ends. Tubular elements are lit with LED lamps strings adjusted inside. Subtle light may enhance atmosphere inside a room and influence its coloration. At night, or when the lights are switched off, there is still some illumination in the room, which gives a sense of safety, and light does not glare. It may be especially helpful in places without windows.



Picture 6.108: Example III: a private cabin





Picture 6.109: Example IV: insides of residential module—day

Picture 6.110: Example IV: insides of residential module—night

Flexible modular elements are useful to shape interiors with curved and flat walls. Division walls may be flexible, curved softly. Annexes will be created in the corners of residential rooms, places to meet and talk to people—along communication alleys. Smoothly curved lines, instead of well-known flat, straight sides, of pneumatic modular elements (armchair, mattress, cabinet) should not create any problems. They are less monotonous then, and annexes may enlarge the space optically (see next sub-chapter).

In the Pict. 6.109 and 6.110 there is shown the habitable area of a module divided into zones with pneumatic walls, lit during a day and at night. Picture 6.111 shows the way how a private cabin may be squeezed into a zone between the main walls. There is a small study on the ground floor, and stairs leading to a hanging bed. The pink area hides a bathroom. The room is divided from the hall with a wavy wall. The view from the hall is shown in the Pict. 6.112. The room looks differently during a day (Pict. 6.113) and at night (6.114).

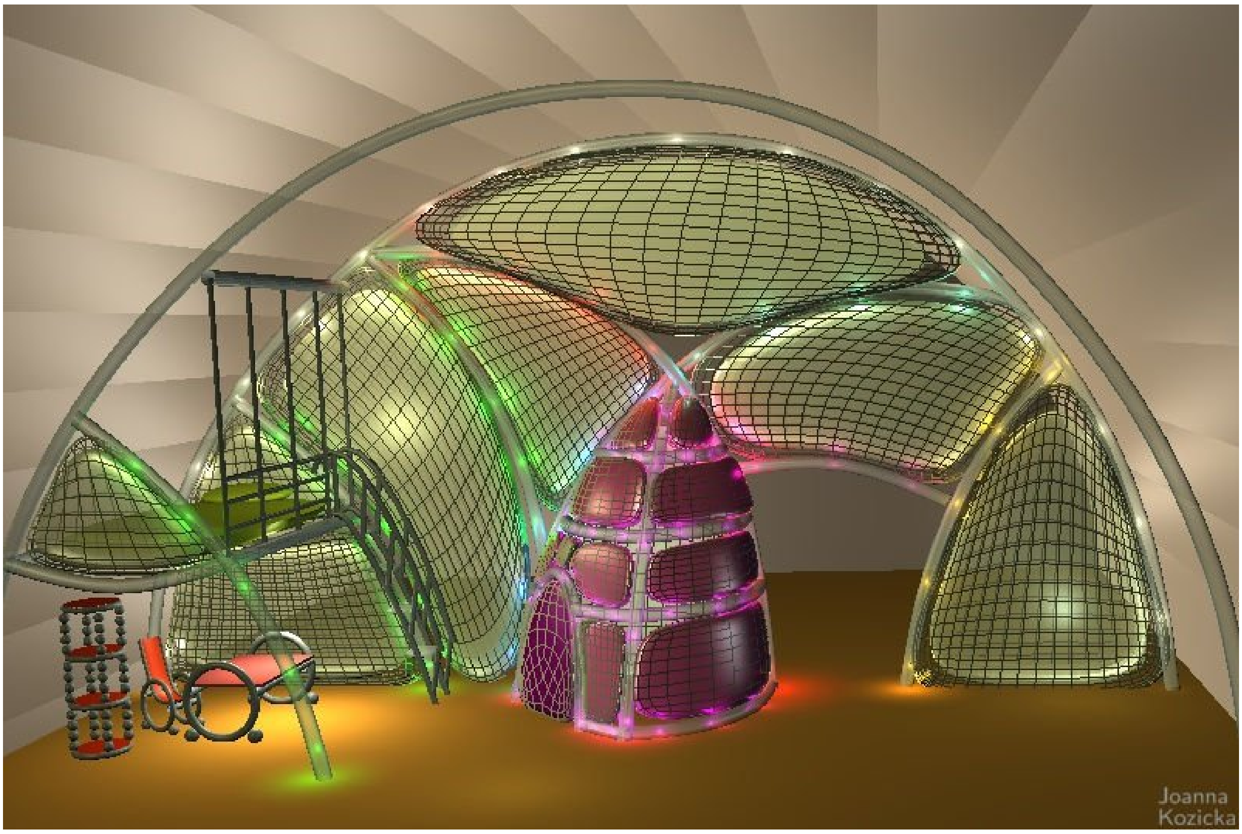
6.4.3 Space perception

Perception is perceiving, the way of receiving and interpretation of sensual impression. There is a real, objective picture of the area, overstriking the layer of associations and subjective feelings of an observer. Having given a piece of habitable area, architect may plan it in many ways designing a room. There may be suggested a cuboid cubature of any, even alternating, height, interiors with annexes, curves, interior entresols etc. All the rooms may be of the same size, however, they may look completely different. Then, they are perceived, each one of such rooms, differently. Thus, **the space perception is influenced by the size and form of the insides.**

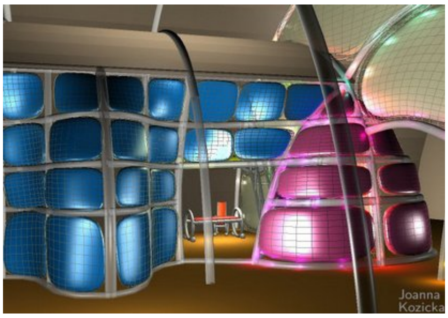
Consequently, having to plan rooms on the identical plan of division walls, there still might be applied a whole variety of arrangement with the help of elements of interior design. There might be different quantity and kinds of appropriable and decorative elements to chose from. This influences the level of density of space with different elements of interior design. The same combination of interior design elements may be set out in different combinations. Thus, the space perception is influenced by the space arrangement.

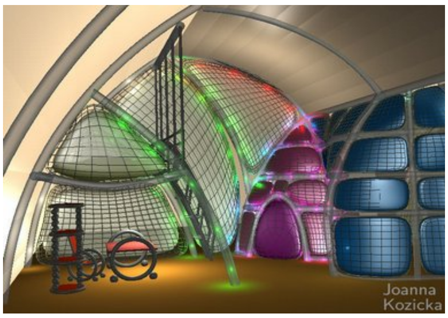
In addition to that, there might be chosen different detail work materials: covers, linings, upholstery, suspended ceilings etc. There might be also suggested many types of illumination: natural and artificial. There may be planned the whole variety of windows, a different number per room, in different shapes and sizes, as well as translucent or transparent division walls. There might be different kinds and forms of lamps planned, with different strength and color of illumination, directed differently. **Thus, the space perception is influenced by: texture, coloration and illumination.**

The same rules applying to habitable are on Earth and on Mars. The same architecture tools may be applied by an architect differently to receive different architectural effects in the area. **In case of Martian base the most important for an architect is to create area perceived as spacious and interesting**. Even if the base will occupy comparatively large area, with spacious rooms per a habitant, perceptional enlarging of the habitable area is of the same importance. This is so important because of the fact that a person living on Earth has the whole variety of impressions and experience from many places seen in the surroundings and during travels over the world. Even a large Martian base cannot replace such variable and huge space. Martian base is going to be the only place for people to walk around without space-suits, the same like on Earth. That is why, the larger the space to perceive, the better. However, it should not be boring, empty space, but variable and alternating. There should be remembered, however, to provide regular doses of impressions reasonably, and to keep to the scale of a human being (e.g. optical enlargement of the height in a small room would be a negative effect). People, for their wellbeing need to receive new impressions, need the effect of a positive surprise. All those requirements may be planned in advance by designing flexible and not self-repeating space in the habitat.



Picture 6.111: Example IV: a private cabin with a bathroom planned in the area





Picture 6.112: Example IV: a hall with the entrance to the private cabin

Picture 6.113: Example IV: the insides of a private cabin during a day

Picture 6.114: Example IV: the insides of a private cabin at night

It is suggested to plan the whole variety of rooms for Martian habitat. Such planning should serve different purposes: to distinguish rooms planned to serve different functions; to break the monotony of limited life environment, which is dangerous for socio-psychological reasons; to individualize specific public places and to enable personalization of private places.

The most important problem about Martian base in to create there a 'sense of Earthly atmosphere'. The long distance from home and impossibility of coming back whenever one would like to will stimulate a strong feeling of longing for home, and for the known world. This suggests that creating similar to home environment could lower this feelings, where an individual would feel comfortable, and at home. On the other hand, artificial attempts to create such surroundings may induce negative feelings. Habitants would live among imitations of things that look differently from the real thing. Technologies used to to shape and arrange the insides of Martian base would be different from those on Earth. Artificial flowers never are looked at in the same way, as natural are. Thus, it may be no sense in attempts to make the same, well-known, and possibly irritating imitation and allow people to remember Earth with the help of pictures, films, photos. The insides, however, should be planned rationally, ergonomically and aesthetically. The new interior design may be received with positive feelings. People may be able to get used to the new surroundings of the specific, new place—Martian base. However, as the author thinks, this predicament is difficult to solve here and now, and stays in theory for now.

The problem of 'Earthly feeling' is here an additional problem. There are different stereotypes of homely look and interior design. Globalisation is responsible for unification of images of a typical house. People are used to cuboid rooms. Thus, it seems that people would feel best in similar surroundings on Mars. Last years show that there are lofts becoming very popular (e.g. in Poland); their popularity increases thanks to their different look, their different division walls, and those walls are in different shapes and of a variable inclination. This may lead to conclusion that a typical cuboid room is not the main reason for people to fell the most comfortably. Thus, recreating in Martian base the same surroundings, to try to ensure the highest possible level of comfort for habitants, does not seem justified.

Size and shape of the insides

The size of habitable rooms in Space bases is crucial. Until now they were too small, that is why they cannot serve as a good example to imitate for Martian base, which should end the stereotypes of tight and uncomfortable habitable space of habitats built beyond Earth. The larger insides of such habitat are, and the closer to Earth's standards, the better the state of being of their habitants is, and the lower level of longing for Earth among habitants (Sabouni and others 1991). In case of Martian base the problem of psychological comfort of habitants is of the highest priority to solve, that is why it is crucial to influence positively the quality of habitable space there in every possible way.

As Grandjean writes (1978, p.85), there is no scientifically proved basis to decide the size and proportions of the insides. Every human being may have different expectations, depending on the culture they were brought up in, or on their individual nature. It is difficult to state once and for all what are optimal dimensions of a habitable space. There is no one, definite answer for this question, even on Earth. Thus, it would be a great problem to define the size of the insides for Martian base.

The size of rooms should be adapted for the needs of individuals—here, habitants of Martian base. Thus, it should:

- be adapted ergonomically for 1/3 g conditions
- ensure the sense of safety and freedom
- be adapted to the number of habitants and the bulk of equipment it should contain, and concern the functionality of the space exploitation.

The rooms should not be too large or too small. Smaller rooms induce the sense of safety (Grandjean 1978, p.85), however, too small rooms induce claustrophobia and a sense of parochialism. Larger rooms give more freedom to move around, however, too large rooms are empty and overwhelming—a human being may feel there lost and lonely. It is very difficult to decide the ideal size of a room, and it is better to plan a slightly larger one, than too small. If life shows that too much space influences negatively people, it may be physically and optically reduced with several architectonic tools. Managing the size of a room is easier with some help of movable divisions: sliding walls, screens, curtains etc. There should be at least one room large enough to house all of the habitants for staff-meetings, to dine together and celebrate occasional parties (Stuster 1986). The size and form of working rooms (here mainly professional laboratories, ERs) should be defined by their functionality.

A human being moves differently in 1/3 g conditions. The lightness enables people to move up higher in the space while walking and jumping. Thus, to prevent people from hitting ceilings with their heads, the height of rooms should not be too small. This is the main problem that should be taken into consideration while planning streamlined constructions. An indirect solution to that could be building ceilings from soft, flexible materials. In lower gravitation conditions people may have problems with keeping balance and with walking. That is why spacious rooms, without any interior design elements may induce anxiety. In case of stumbling it would be difficult for an individual to find something to grip to keep balance and avoid falling down.

Taking into consideration the size of rooms, there are three main factors that influence spatial perception: the proportions of the insides (Grandjean 1978, p.86), the maximum distance of the observer from the wall, and the number of windows and transparent divisions (MSIS 1995). A room is larger when the maximum distance between the opposite walls is larger. An oblong room seems smaller from square and round rooms. Windows enlarge rooms visually; this is the case concerning any openings that give view into larger distance, e.g.: skylights, transparent and openwork divisions. The size of rooms may be perceived as larger because of structural connections with terraces and balconies.

It is suggested that rooms should be different from each other, because modularity and repetition influence negatively psychical comfort. To make the rooms in base interesting they should be unique. The most the rooms differ, the more possibilities are available for different impressions to receive for an individual. Architect may achieve such effect with e.g. introducing different lines of divisions in habitable space to divide space into separate rooms, floors and zones; introducing changes into the level of floors and suspended ceilings; arranging retractable landings on different heights; sliding or movable walls. Any possibilities of introducing changes into restricted and limited habitable space are welcomed

(Evans and others 1988). A form of the room should enable functional furnishing in it, and in different configurations. Larger rooms have much more potential to be arranged in such a way. The habitants of Martian base will take a limited amount of personal belongings with them, however, comfortable and spacious rooms should be prepared for them. As Evans and others write, people living in limited and confined (ICE) life environment spend most of their free time in their rooms, alone. To avoid overwhelming effect of empty rooms, the author suggests to divide them with colorful divisions into the zones for changing clothes, relaxation, private work and sleeping.

Perception of space in a room is influenced by its shape. The insides, limited by the walls with curved lines that hide some areas, are visually larger (Dubbink 2001). Straight, cuboid rooms have restricted, finished form, without any mysteries and interesting annexes. Everything is visible at first sight. Such rooms seems more boring. Divided partially into two, visually connected, an area seems more spacious. A division should be subtle—a change in the floor level, an openwork wall etc.

First of all, a form of rooms depends on the shape of the building, of the base. The problem of curves is elaborated in a previous sub-chapter. Technology chosen to build division walls also influences the form of rooms. Some types of constructions are more rigid, others allow more flexibility for shaping structural elements. For example, Superadobe constructions create a form of elongated domes only; metal is considered the most practical to make cylinders of a medium diameter. Stone-masonry and underground buildings are considered as those that give more freedom in building. The highest level of creativity may be achieved while planning the interiors of buildings: drilled in ice, made from Shape Memory Plastic, and exploiting pneumatic elements. Interiors of such buildings may have completely irregular shapes, they may be written in curved lines, even in all three dimensions. This gives many opportunities in planning interiors to an architect. On the other hand, however, too much complexity may create difficulties to build the structure and cause the insides to become too characteristic, and introducing changes would not be easy. Furnishing such structures may become complicated and limit flexibility of the insides.

Apart from the inner divisions, space perception is shaped also by objects inside. There are many elements of interior design: pillars, balustrades, furniture etc. Many objects filling the insides may create the sense of tightness for space and reduce the insides visually (Grandjean 1978, p.86). When a room requires many supporting or accessory elements, it is worth to build them with transparent or framing constructions to make them less overwhelming. A room may be considered larger visually by specific composition of interior design elements. There are many examples in architecture on Earth of the so-called perspective illusion. A choice of a spot the most often used by the observer may help to introduce such interior design elements that would create an impression of larger distance among them, e.g. with a help of rows of columns moving closer. Perspective illusions of a greater distance may be achieved also with a help of walls' decorations, e.g. artificial windows and passages, pictures with perspective illusions etc. The illusion of a larger room may be created also with a shape of a room, e.g. by a slanting ceiling, or a project of elongated ellipsis, instead of a circle or a rectangle[16].

Texture

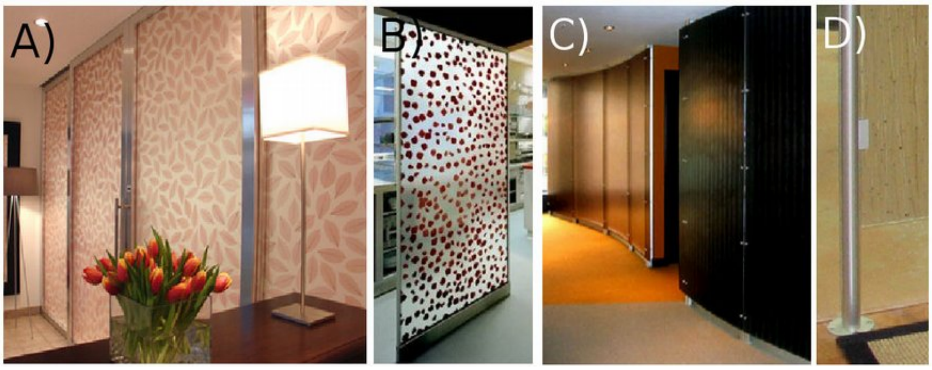
A texture is a characteristic surface of an object, which depends on the material and its processing technology. Texture influences the emotional reception of the interior design elements—they may seem nice to touch, neutral or repulsive. Such perception is usually connected with the material that is used to make an object, however, imitations may deceive senses. The most repulsive are considered materials that seem cold. They are materials which characterize with high energy conduction, e.g. metal, stone, concrete, glass. Especially repulsive materials to touch are considered those that are very smooth, slick and shiny, like sheet metal, stone slab, crystal. The most attractive are materials that seem warm. They are materials of low energy conduction, e.g. wood, processed wood materials, paper, fabrics, wool, fur, leather, plastic, sponge. The most attractive to touch are considered soft and matte materials, mostly fabrics, wool, fur. The feeling of soft surface of the interior design elements reassures people that in case of hitting into such surface it would not be too painful. Such perception is very important in Martian habitat, where people, in lower gravitation conditions will be more helpless while moving around. Surrounded by soft, flexible and elastic materials people would fell safe and secure. Such materials are usually good acoustic isolators, too, what is their additional advantage, especially appreciated in ICE. However, their huge disadvantage is the difficulty to keep them clean. It is of the utmost importance for a Martian base to be kept tidy and clean. It is as such, first of all, due to: hygiene; the impossibility of replacing permanently dirty elements for new ones; the need of keeping the impression of cleanliness, what is very important for the sense of psychological comfort; labor-intensity, energy, water and cleaning supplies consumption. Thus, it is suggested that the surfaces of interior design elements should be as easy to clean as possible. The next matter here is the aesthetic of interior design. A texture also influences the acoustic and illumination of the insides (MSIS 1995). Small roughness is the best way to muffle sounds. Thanks to such a texture, the acoustic of the insides may be significantly improved, it muffles sounds and protect people against irritating reverberations. This is also a good way to reduce reflections on the surface of materials, protecting habitants from a dazzle.

There are available many different materials now, which may be used to make interior design elements. Processing technologies are improving all the time to make more durable materials, with many different textures. As fabrics are materials with the most welcome textures, they are worth introducing to the insides of Martian base. They are easy to pack tight, they are light and thin. However, it should be pointed here that their exploitation should be limited for small elements, because they are easy to get dirty and they should be washed with washing supplies. They should be rather used to make some easy to remove elements of furniture, as cases for seats, curtains, coatings for frame construction etc. There should be chosen fabrics which are easy to clean. Such fabrics are e.g. polyester, which is warm and rather smooth. Although they are smooth, their surface is not dazzling. On the other

16 Architectural illusions are based on e.g. a plan of Capitol Place in Rome by Michael Angelo, St. Peter Place in Rome by Bernini.

hand, they may be easily arranged to create such protrusions and concavities, which would not require too much effort to clean them, and at the same time they would create a texture substitute. Apart from this, plastics are light, and thin panels and extremely thin foils are easy to make required elements from them. The elements made from this material are easy to pack. Resin is also a kind of plastic. Some of them are transparent. There may be different materials submerged into resin (e.g. of a plant origin—wood, fiber, stalk) to create structural wall panels or door-wings (Pict. 6.115). They are used also to make very remarkably sound absorbing wall panels (e.g. Soundwave Offecct AB).

The easiest way to create the impression of softness of interior design elements is to paint them in a way to create an illusion of tiny chiaroscuro. It may be achieved by spraying a wall with two paints of the same color, but in different tinges, in different brightness. The use of more kinds of paint may create a more natural effect. Wall-covering with wall papers requires more effort and a use of a tested material; it is also more difficult to cover rough surfaces. There could be also used a double-layer wall paper: the under-layer could be rough (it may be a fabric made from natural or plastic fibers), the surface-layer could be transparent (e.g. made from foil) to show the under-layer's interesting texture. Such a wall could be illuminated with specific light from a side or from under the wall-paper, to make the texture more visible.



Picture 6.115: A,B,C—examples of different resin panels, D—a fastening detail

(www.3- form.com)

There are many elements of interior design that may be made from bamboo. It is a kind of fast growing grass which stems become woody. It may be used to make fiber and paper, too. Bamboo is the only source of wood that may be economically acquired on Mars in BIO LSS. Bamboo may be used to make wall and floor panels, mats, doors, pillars, balustrades, fences, entresols, furniture, frames etc (Pict. 6.116).

Picture 6.116: Examples of interior design elements made from bamboo, with a nice texture to look at (Natural Bamboo Products Ltd.)

Color scheme and illumination

Color scheme and illumination are very potent architectonic tools, which will influence deeply the physical and psychical comfort of the habitants of Martian habitat. Physical and psychical comfort of Martian crew is the main factor, which the mission success depends on. Light and color play a very important part in an individual's life. The most sophisticated human sense is the eye. That is why the visible world influences so deeply a human being's emotions and feelings. Bright illumination in a room gives a sense of confidence, because everything around is visible. Darkness, on the other hand, causes anxiety and divests people of courage. Colors help to recognize surroundings, and are nice to look at. Warm colors create a sense of cosiness, they can create different impressions: green—peace of nature, blue—sky distance, flowery meadow enraptures etc. That is why the right choice of colors is of a great importance.

The analyses of color perception by people, conducted by Wise and Wise (1988) made it possible to define the general rules of appropriate, and positively received by people, choice of color scheme and illumination for the interior design of Space habitats. The synthesis of drawn conclusions led to create many points in MSIS standards (1995) for orbital stations. Those orbital stations differ from Martian base in many points, that is why the author centers upon defining project guidelines appropriate for Martian base. There are also suggested many different ways to create interiors with flexible color scheme to search for the most economical and effective solutions. An architectonic project of Martian base should contain a suggestion of interior color scheme. It should also takes into consideration introducing changes into suggested colors. Kinds of materials, creating surfaces of elements, have a straightforward influence on the way of changing color scheme of the insides. When there is a tiny roughness on the surface, it is usually good for painting and wall-covering. Fabrics may be used to make exchangeable and colorful coatings and coverings of different elements, e.g. as cases, coverings, curtains. Smooth surface is more difficult to cover with paint. It is usually coated with varnish. There may be attached coatings that exploit electrostatic phenomena. They are made from very thin and light foils; foils may be tinted in different colors and stay partly transparent. As Evans and others (1988) write, a possibility to change the colors of interiors at polar stations was highly appreciated. However, a transportation of paints to Mars seems uneconomical. Still, there is a possibility to process pigments *in situ*. There are two additional problems: chemicals in the air during the time of drying of paints, and it is impossible to recover the under-layer. That is why the most economical seems the use of coatings made from foils that are easy to apply and clean, or fabrics suitable for washing in the washing machine. Such coatings may be used and reused in different parts of Martian base and in different arrangements, which is an easy way to introduce changes, to keep the base clean, and to achieve a high level of flexibility of the color scheme.

A room is received positively, when everything is visible in it. It is possible to achieve by the use of adequate arrangement of colors while planing interior design. There are distinguished three main groups of interior design, depending on the size and importance of elements: a background, larger, and smaller elements of interior design. There are different recommendations considering each group. Brighter colors are more visible. Larger elements are also more visible, because of their size, so there is no need to make them out into the first plan more with colors. Thus, their preferred color scheme is rather pale, in contrast to smaller elements. Smaller elements are more difficult to see, to make them out in a room. Thus, smaller elements, to distinguish them among all of the elements of interior design, have to be brighter, more contrastive. The strongest contrast is made with the use of black and white colors. A good prominence in the insides is created by the use of a very bright, or very dark, background. People feel better among elements of background in light colors, not dark. The conclusion here is that light elements on a dark background seem larger and closer, and dark elements on a light background—smaller and more distant. A light background influences spatial perception of a room; it helps also to create an impression of a nice and cheerful room. It is difficult to make out shadows on the dark background, which are crucial to create an image of depth, and a feeling of dimension. A light background influences perception and enlarges space on condition that the elements of furnishing are not lighter in colors. A human being feels bad in a congested room, that is why such visual enlargement of a room is received positively in general.

Background: it is the main element that influences positive reception of a room. It should be very light, less saturated. More saturated colors would interfere with perception of smaller elements of interior design, what would cause anxiety. The only exception is blue color, which is perceived specifically—the higher is the saturation of blue color, the larger impression of space is (an impression of the spacious sky). A background should be homogeneous. Especially inappropriate is contrasting large areas of different colors, because it interferes with perception of the whole interior, and may create an indirect dazzle effect. As the author points out, however, it does not mean the need to use one color only, e.g. a soft chiaroscuro, similar to that under the crown-trees may be received very well. A background may change during the day, mostly with some help of main sources of illumination creating other chiaroscuro effects, or secondary sources of illumination that can change the color of background—changes in time influence the effect of dynamic, and the insides seems lively, as it is on Earth.

Larger elements of interior design: they should be darker than a background, and be more saturated, to make their shape visible in the background elements. They are perceived positively, when colored in shades of brown—similar to that of wood, and green—similar to that of leaves. Configurations of those two colors are received best, among other configurations of colors of interiors, no matter what are their functions. Those are colors that influence especially well the mood, however, too wide exploitation of them would be monotonous. Thus, they should be applied in places where architect would like to create an especially cozy feeling. Larger elements of interior design should be stained with at most several shades of those colors to avoid a color mess, which is received negatively.

Smaller elements of interior design: they should be stained in contrasting, bright colors, to be visible on the paler background; they should be more saturated, and be very bright or not bright at all. They should be also kept in some chosen tones, to avoid chaotic coloration, and a sense of an overwhelming mess in a room, especially when there are many of those elements. Smaller elements of interior design may point to their function with their colors in such a way: one color for elements that are designed to help people to move around (handles, railings), one color for kitchen utensils (a microwave, a kettle, cutlery handles) etc. That way the space would seem tidy, however, those elements do need to be in one specific color: it is enough to choose one dominant color for them to underline their affiliation to one of the groups.

The above rules should be analyzed while planning specific rooms in Martian habitat, taking into consideration their functions and size, quantity and area occupied by larger and smaller elements of interior design. When a private cabin is considerably big, and, due to some restrictions, there would be a scarcity of elements, color enhancing would be a very good measure. It would lower the feeling of emptiness and deprivation from many objects for everyday use, that may be longed for. One of the measures of color composition for such a room is to cover one of the walls with a photograph wallpaper or a large poster, best showing a landscape from Earth. Such landscapes may influence positively people confined to Space habitats, because they create a depth of a picture that enlarges the room, and make impression of being close to the well known nature and to the open space. However, a photograph wallpaper may make it difficult to plan to design a color for the rest of elements of interior design, and may become boring very soon. Depending on the colors in such a picture, there would be required specific colors for those elements. What is more, as it may get boring, furniture should fit different pictures that are planned for the room, or be composed from such elements, that may be removed and replaced with others, enabling to make a change in a color scheme. Accordingly, the best choice for furniture color scheme would be: wood—generally accepted, black or white—well contrasting with any background, or shiny surfaces, e.g. metal. The elaborated above rules of color scheme exploitation have been used to design optimal color benchmarks for interior design. Zausznica (1959, p.474) gives some examples of such colors configurations.

As it has been ascertained that a shade of the color does not influence human behavior, introducing changes in flexible interiors should not create any deterioration of the space quality. Red and green armchairs' cases should be received in a similar way, when saturated and tinted the same. Thanks to this, replaceable cases would really diversify interiors of the habitat, without deteriorating their emotional perception. When a room is designed for work that requires concentration, colors should be chosen very carefully and used moderately, to avoid distraction and anxiety. More saturated colors may be applied successfully in places anticipated for a short stay, e.g.: entrances, halls, toilets, subsidiary rooms. There, saturated colors would serve to enhance the architecture (Grandjean 1978, p.253).

Wise and Wise (1988) defined some general standards for interior design. Putting those standards into consideration, an architect may be able to create a nice and cozy place, easy to be liked. However, it does not mean that different color configurations are always received negatively. NASA MSIS (1995) standards apply mostly to congested and tight Space habitats. Any contradictions towards those standards in spacious private quarters in Martian base should not create consternation, especially when a color scheme is chosen by the occupant. Adaptation of space to the needs of an occupant of the room is the priority here. Very often people need their room to be cozy and warm, and not spacious, and they need a dominance of their best color, etc. Personalization of private space should be taken into consideration with respect of private needs. That is why replaceable cases and linings should create many opportunities for color decoration of interiors. However, Wise and Wise (1988) suggestions are worth taking into consideration in public, widely available areas. There should be applied generally accepted rules. Apart from this, it is easy to change coloration of large elements of interior design in light and less saturated colors with the help of different kinds of illumination.

A project of Martian base should include a suggestion of optimal illumination of the base, its default configuration, and show some possible to introduce changes with the help of elements of the default illumination. There should be planned sources and kinds of illumination in the habitat.

Kinds of sources of illumination: There are two basic types of illumination: natural and artificial. Natural source of light is the Sun. The moonlight is so faint that it is impossible to tell colors apart in this light; saturation of black and white colors is possible to distinguish only in such conditions. There are two moons that go round Mars. However, they are much smaller then the Moon, and despite of their tight orbits, they are much smaller objects in Martian sky, than the Moon is in the Earth's sky: Phobos is 1/3 of the size of the full Moon, and Deimos is visible as a bright star would be. Thus, nights are much darker there than those on Earth.

The atmosphere of Earth is much denser and there are many clouds in there. However, Martian sky is much darker, because its distance from the Sun is larger. The Sun on Martian sky has smaller perimeter, and it is not going to enhance the mood of habitants, as it does on Earth. A color of the sky will be received as unnatural, because it is pink, and not blue. To create a light and cheerful atmosphere during a day in the habitat, as it is on Earth, there should be exploited some tools for the purpose.

Picture 6.117: Parans Daylighting System for transportation of concentrated Sun-light via optical fibers to the emitters inside (Parans Daylight AB)

It is possible to increase the intensity of visible radiation with e.g. mirrors. They could concentrate Sun-light and direct it to the insides of habitat; next step would be a dispersion of the light to illuminate the area. There could be also used a transmission system of optical fiber for the purpose (Pict. 6.117) (Brownell 2006, s.210). Each solution requires adequate equipment, which should be transported from Earth to Mars. There is possibility to make mirrors on Mars from local sources, however, the required precision would be difficult to achieve. Typical mirrors are heavy and may break apart. However, modern expandable constructions with optical elements made from SMP are the real alternative here (see Pict. 6.29). When such a system of concentrating daylight would not be planned for Martian base, there would be too dark, even during a day, to grow plants or to create an atmosphere of a cheerful day. The installation of such mirrors, even if expensive, would become the best financial solution when compared to the consumption of energy and transportation of lamps from Earth, because natural light is for free. There should be also taken into consideration protecting form deteriorating dust—covers for the mirrors. Making many windows and transparent walls to illuminate the insides better is not the best solution, because it would influence the surface of the outside coating; in consequence too large part of the surface would be left without necessary anti-radiation coating.

Natural illumination (Earth daylight) is the safest for human eyes, and influence in the best way their mood (Mieszkowski 1975, p.25). However, treating natural light as the only source of illumination in Martian habitat is impossible, mainly because of dust storms. During those weather conditions mirrors and systems of optical fibers are not enough to illuminate the insides properly, so there are required artificial sources of light. They are required also to illuminate the insides during Martian night.

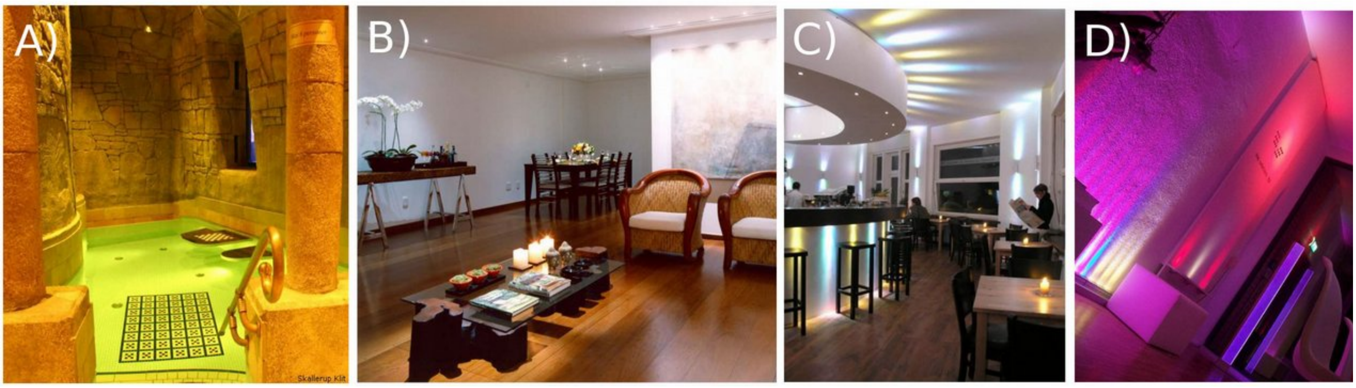
There are different sources of light. There are listed here three main types of those sources: light bulbs, gas-discharge lamps, and light-emitting diodes. Those three types of light-sources include many different lamps of different illumination characteristic. They differ, among others, with: intensity of light, efficiency and tinge. There should be chosen for Martian habitat sources of artificial light, which apply best to such criteria: they should be productive, cheap for transportation (small and light), characterizing with long obsolescence. Their additional advantage would be if it were easy to manipulate with their intensity and tinge to create different light-effects, without the use of additional lamps. Lamps designed to create good visibility inside should bring out real colors, thus, their spectrum should be similar to the Sun spectrum (the modulus of bringing out colors should be as close as possible to the maximum value—100). MSIS (1995) suggests that in Space habitat there should be used mostly white light, because people and objects look natural in it, and color-codes are read properly in such light.

The most efficient are sodium lamps. However, ordinary sodium lamps emit yellow-orange monochromatic light. Sodium lamps emitting white light have been successfully created, though their production is very complicated, and thus, expensive. Because of these, such sodium lamps were not introduced to production (Gabryelczyk 2005). During tests in Russian BIOS-3 it was decided that a human being cannot stay a whole day in the light emitted by ordinary sodium lamps, because it induces a great psychical and physical discomfort (Lewandowski 2000). NASA (MSIS 1995) standards forbid exploitation of monochromatic lamps in Space habitats.

Picture 6.118: The ways of optical fibers exploitation to illuminate the ice insides of the Ice Hotel (icehotel.com)

Contemporary a compact fluorescent lamp gained great popularity; it is called an energy-saving light-bulb. It is about five times more efficient than an ordinary light-bulb, and its planned obsolescence is longer. However, fluorescent lamps do not bring out colors well. Only fluorescent lamps of new generation can emit light white enough (the modulus value: 80-95). Their main disadvantage is their size. They are large and would occupy much more space in the transportation rocket to Mars than e.g. halogen lamps or metal-halide lamps. Halogen lamps are more efficient than ordinary light-bulbs; their construction is simpler than of the fluorescent lamps, however, they have half of fluorescent lamps efficiency; they can be turned on and off many times, and do not wear off too fast. Halogens may be fast and fluently dimmed. Their turning on and off time is short. Metal-halide lamps are high pressure gas-discharge lamps, producing high light output. They are long lasting lamps. Halogen lamps and metal-halide lamps produce white light (warm or cold) and bring colors well (the modulus value goes up maximum even to 100) (Gabryelczyk 2005). That is why they seem an ideal solution as artificial light sources for Martian habitat.

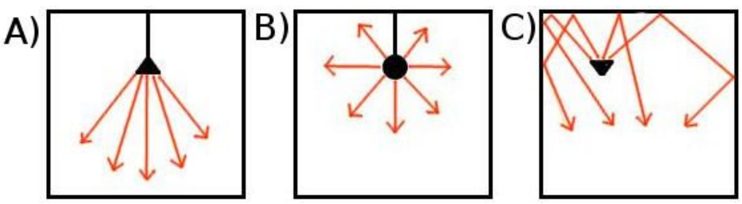
Apart from efficient and strong light sources which should ensure good visibility in Martian base, there could be taken into consideration also lamps that produce lower light output, to use for supportive and decorative purposes. There could be the same types of lamps, but producing lower light output. That way, the same protective panes could be used to insert the same types of lamps, but with lower light output—this solution ensures more flexibility. However, due to economic reasons, for secondary light sources there should be chosen energy saving lamps. They may be light-emitting diodes, so called LEDs. They are small and characterize with incomparably longer life than any artificial light sources mentioned above (after 100 000 hours of their work their light output goes down in half of their beginning value, and stop giving light after a very long time) (Raczyński 2005). Their light bandwidth is relatively large in comparison to their light output. They are real energy-savers and when it is required, they turn on and off at once, they can be fluently dimmed, and their tone may be manipulated. That is why they are good for projecting moving pictures.



Picture 6.119: Examples of illumination: A,B) optical fibers (swiatlowody.com) and C,D) LED lamps (vossolutions.com)

LEDs and halogen lamps are used in light technologies as light-generators for optical fibers. With optical fibers light may be directed in different places in a room with one light source only. Optical fibers are thin, light and flexible cables. They would occupy only a small part of transportation hatch, and in the habitat they would be distributed in different configurations. Different tones of colors in optical fibers are achieved with colorful rotating filers (Światłowody 2006). The atmosphere of the interiors may be created in the same way—with the help of LEDs and optical fibers. There are produced different types of those light sources: point fittings, linear fittings and pane (screen) fittings. Because a point fitting is very small, those types of fitting may be used to create letters, words and pictographs. There are two types of optical fibers: tip-producing light output, and surface-producing light output. Surface-producing light output optical fibers create linear light. Because they are flexible, they may be used to make straight and curved lines. Optical fibers transport only light rays, so they do not produce heat as light-bulbs do, so they may be used for illumination of e.g. ice surface (Pict. 6.118), and others (Pict. 6.119 A,B). Light generator, from which optical fibers are distributed, may produce light in different colors. LEDs produce similar light effects as optical fibers do, but to achieve more powerful illumination, LED with higher modulus value is needed (but of the same size), or thicker bunches of optical fibers (they are heavier then). LED lamps are equipped with light-bulbs of lower modulus value, that is why they need smaller batteries, and they may be movable. In case of optical fibers they should be suspended in different configuration, what requires more effort. LEDs are used as point lamps, light emitting cables and screens (halolamp 2005). Different interior design solutions with the use of LED lamps are shown in the Pict. 6.119 C) and D). LED screens emitting light may be used in Martian base to project wall pictures showing nature to enhance the mood of habitants. A brightness of the room may be more powerful (without any additional light sources) with the use of light reflecting surfaces—in bright colors, shiny surface, mirrors.

Illumination types in Martian base: There may be distinguished three types of illumination: general, local and spot-lights. They play different functions in a room: general type of illumination serves good visibility, making the room brighter; local—to illuminate an important place (usually working space of to display an element of the interior design); spot-light source is used mostly to create interior atmosphere.



Picture 6.120: An outline of basic kinds of general illumination of the insides: A) direct, B) dispersed, C) indirect

There are three basic kinds of general illumination: direct, dispersed and indirect (Pict. 6.120). Apart from this there are exploited mixed solutions (Grandjean 1978, Mieszkowski 1975). Direct illumination is best to illuminate a place of event where there is work done. It is efficient and economic. It would seem that this may be the best solution for general illumination of Martian base. However, there should be taken into consideration also levels of indirect illumination of walls and ceilings—if it is too low, shaded background would create perception of congested, smaller space, and interiors would seem murky, gloomy. Such phenomena is very unfavorable to socio-psychological considerations. Dispersed illumination brighten a room in every direction, illuminating evenly all surfaces. It influences perception, an observer can see a room as a large, cheerful and spacious place. That is why it seem as a good solution for illuminating Martian base, especially public and recreational places. For this kind of illumination there are used warm fittings to protect the eyes against direct dazzling. Indirect illumination means that the light source is directed into the ceiling, light beams reach ceilings and walls first. That way light reaches a place of event partially only, and it is not illuminated fully. This is inefficient illumination. Most of the light is directed to illuminate background. It may be used on Mars only when direction of light sources may be changed, and upright direction is an optional configuration. Such illumination protects best against a dazzle effect and creates warm atmosphere in the room. Additionally, because background is illuminated efficiently, a room is perceived as larger. Indirect illumination is appropriate for recreational functions and those, where screens are in use (computer screens) and too much general illumination is not recommended.

A kind of general illumination, a number of local light sources and an orchestration of spot-light sources is assorted for a room considering its function and work to be done in the room. For example: dispersed bright illumination is highly recommend for public places, recreational places, sports facilities and dining-rooms (MSIS 1995). Working rooms with computer work-sites should be illuminated indirectly and should be equipped with the right quantity of local light sources. Alternatively, general light sources may be manipulated to replace local light sources and illuminate work-sites, at the adequate angle.

Function of illumination: There may be listed different functions of illumination in Martian base:

- illumination of the base from the outside,
- providing good visibility in the interiors,
- providing illumination at night,
- supporting day and night cycle for work and rest,
- perceptional enlargement of space,
- introducing variability in restricted environment of the habitat, assuring diversification and breaking monotony,
- creating interior atmosphere of the base,
- adaptation of the insides for different celebrations,
- informational function.

The base should be illuminated from the outside to be seen better from orbits by Martian satellites. Additionally, it would be easier to find by crew members coming back from their missions. A shape of the habitat could be exposed better, different types of illumination could be chosen depending on the construction of habitat. If there are many windows and transparent barriers, it could be illuminated from the inside and, thus, well seen at night. When it is an underground habitat, or coated with thick ground layers, its illumination would be pointless; lamp sources around the base should produce enough illumination. Constructions with visible outside cover could be illuminated and be equipped with reflecting elements to increase its recognizability from a distance. Due to economic reasons, the best for the purpose seem sodium lamps fitted outside. The light they produce would be received by habitants good enough, despite its distortions in tones, because the whole planet is orange.

The most important is for the illumination of Martian habitat is to provide good visibility inside Martian base. It should be bright during the day in there. The best option is when the color of illumination is close to that which is common inside households on Earth. It should provide physical comfort—to this tone of light people's eyes are adapted and it is the wealthiest color, and psychical comfort—a human being feels good in the light similar to that on Earth. The best option would be the Sun-light from the outside. As Mieszkowski (1975, p.31) says, a human being working in conditions of the daylight is 10-20% more efficient than while working in best possible artificial light. However, the Sun-light on Mars may produce not enough power to illuminate the interiors optimally. Then there is the place for supporting artificial light. Achieving good visibility conditions inside the base is the priority here. Depending on the functions of separate rooms, there are different standards defined. For the sake of hygiene for human eye working differently while doing different tasks, there is defined specific light power for different places (Mieszkowski 1975, p.34). MSIS (1995) defines similar conditions for Space habitats. The norms could be verified for the specific model of Martian habitat. Hight level of brightness inside the base assures good visual reception and may create cheerful atmosphere. It is necessary to save energy consumption, so power sources of light should be exploited only when absolutely needed. As MSIS (1995) states, to ensure good morale of the habitants there should be bright and powerful illumination in at least some of the insides. This standard applies to such functions as: food preparation, recreation, personal hygiene. A working-site requires specific type of illumination. Standards define its power as the one, which is required by specific function and work precision. The most common working place in Martian base is a counter top, a desktop, which requires especially powerful illumination. There are only some rooms which apply to that standard: ER, workshop, kitchen tops. In computerized base, where paper is to be a luxury, working-sites would not require powerful illumination, on the contrary—too much illumination may make the work with computers and in front of screens more difficult. There should be remembered that one counter top may be used for different tasks. Such places could be illuminated by the kinds of lamps which brightness is easily manipulated, dimmed, as e.g. halogen lamps. For private cabins MSIS (1995) suggests the use of light sources which may be manipulated by an individual occupying the room. Good visibility conditions inside is achieved also with even illumination, i.e. the relation of the less powerful illumination to the largest area (Mieszkowski 1975, p.36). As Grandjean (1978, s.229) writes, researches conducted on human physiology show that optimal visibility conditions and the feeling of optic comfort depend mainly on the dispersion and contrast of the brightness of large surfaces in the sight area.

The next related problem to the above subject is illumination of the base at night. Socio-psychological considerations direct to the supporting of a day-night cycle in an outer-space habitat. Thus, the working day and relaxation at night should be taken into careful consideration. One of the means to support this regimen in Martian base is the diversification of illumination for the day one and for the night one. There should be bright during the day inside, as it is on Earth, and at night illumination should be dimmed. Complete darkness should be avoided for the sake of safety and socio-psychological reasons, and for the part of the crew working at the nigh-shift. In private quarters every individual should be able to manipulate interior illumination according to their needs. In public places, especially in halls and passages, light should be dimmed at night. The best kind of night illumination is producing less powerful light, of low modulus value, such as created with LEDs. Some phosphorescent elements would support such illumination. It is a good solution to the problem of diversification illumination for the working day, and less energy consuming—for the night-time. Night light's dimmed brightness would be able to illuminate darkness well enough, and at the same it would not dazzle eyes. It could be arranged to create interesting light effects (e.g. a starry sky)and to inform (on the edges of furniture pieces or other barriers on the way). Phosphorescent elements may be stuck in different places, that is why they are more flexible; it is a better solution to painting some places once and for all. Where there are many windows and transparent divisions, specific night lamps should be enough. Where there are not enough windows, or any at all, there—illumination should be programmed to produce powerful light daily, partially dimmed in the evening, and dimmed at night.

Picture 6.121: A system of lamps in calming colors Therapie (snowlabde- sign.com)

There should be planned illumination easy to manipulate and change—flexible. That way different atmosphere would be created by an easy change of: direction of a lamp source, direction of a light beam, its color. Flexible illumination would make it easy to introduce changes in the space of ICE, what enhances psychological comfort of its habitants. Flexible illumination of the insides allows them to be shown differently. A change of illumination changes the whole reception of space, e.g. it changes color, shadows may deepen, space is divided into parts of diversified saturation of light etc. With the help of different light sources different atmosphere may be created. Warm light gives a cozy look of a room, strong light creates strong chiaroscuro what enlivens a room, stimulates it; dimmed light, dispersing shadows, may calm down and invite recreation etc. Illumination may shape atmosphere of the insides in different ways: with its brightness, its reach, with its place of fitting and direction of the light beams and their dispersion and color. Most of standards applying to light influence on a human being may be decided by heart and by experience. Researches conducted in laboratories may be of some help as well. Illumination system Therapie by Andre Keilani based on studies on light and color therapy is one of the examples of such laboratory researches (Pict. 6.121) (Brownell 2006, p.214).

Picture6.122: A lamp with integrated light sources, which may be directed differently

Picture 6.123: System BLUEmotion where the light source is easy to manipulate to create different light effects (Trilux)

Light may be used in a base also for informational purposes. Light panels, signposts, warning signs etc. may be really helpful there. They may warn about Sun storms, direct to evacuation exits, inform people where there are some crew members, show the menu, signal a keep-out warning and permission to enter etc. Signaling illumination do not require strong and powerful light sources, but colorful and contrasting lights. Their energy consumption would be low, especially when they would be turned on only occasionally, to signal exceptional situations. Such lamps are small and produce light occasionally, so they do not influence much the interior design of Martian habitat. However, they may be planned at the stage of designing such a base. Illumination of the base may also play such informational part, e.g. tones of one dominant color may be applied to areas for different functions—different tone in halls and passages, and different tone in working places; or one tone of illumination may shows the entrance to a room of specific function—as a frame of the door, a light picture above the door etc. The choice of lamps should be carefully prearranged, especially its tone and saturation. Light present all the time in one area, which do not signal any specific and important information (e.g. signaling the specific function of a room), should not be very strong. Additionally, it is worth to take into consideration codes of light color—some colors are connected strongly with specific information, e.g. red—alarm, green—permission, blue—information, yellow—warning etc. Red lamps would warn about Sun storms, and green arrows direct to the shelter or to a safe place. It would help to create a scheme for the informational illumination of the base. As Zausznica (1959, p.258) writes, a kind and strength of a sound influences individuals' ability to recognize a color. Such phenomena would be adapted to co-work with the warning scheme there. That way sound would bolster eye reception, focused on specific color information codes. Thanks to that effect, color illumination would be less intensive when needed.

Because of the role which colors and illumination should play at Martian base, there should be ensured maximum flexibility of their exploitation. This may be achieved with the introduction of the author's rules:

- Colors and illumination should be planned as default for interiors of Martian base, according to the standards considering the influence of colors and light on perception and feelings of people. The light colors should dominate, especially for the background, because of:
  — possibility to change their tone and brightness with the help of illumination,
  — possibility to enlarge a room optically,
  — stronger illumination of the insides with less powerful light sources, not as strong as they should be for darker colors,
  — effective dispersion of light beams to brighten more elements of interior design,
  — creating cheerful atmosphere, and clear and clean insides.
- A change in color scheme of the insides may be introduced with:
  — flexible illumination,
  — replaceable linings, which are light, thin and easy to be transported as well as to be fixed, e.g. electrostatic foils, and fabrics as curtains and cases,
  — the use of various movable elements for interior design, e.g. wall panels, decoration elements for large surfaces.

  Painting walls seems too uneconomical for Martian base, and unhealthy in such a habitat.

- Flexibility of illumination may be assured with the help of:
  - — movable light sources,
  - — light sources that may be directed flexible,
  - — light sources with different colors,
  - — light screens, panels,
  - — surfaces reflecting light,
  - — surfaces dispersing light.

Examples of flexible illumination:

(a) Light sources in rotating fittings (Pict. 6.122). With a change of light direction, illuminated place is changed, which is illuminated stronger than background—different place is distinguished, e.g. a picture on the wall, working-site, or a room is illuminated with indirect light.

(b) A programmed lamp equipped with several light sources which may be programmed variable; reflecting surfaces which may be directed variable. An example of such intelligent lamp is BLUEmotions (Turlej 2007) by Trilux. Light effects created by this lamp are shown in the Pict. 6.123.

(c) The use of many light sources producing less powerful illumination, which may be turned on an off in different configurations. LEDs and optical fibers seem perfect for such a purpose.

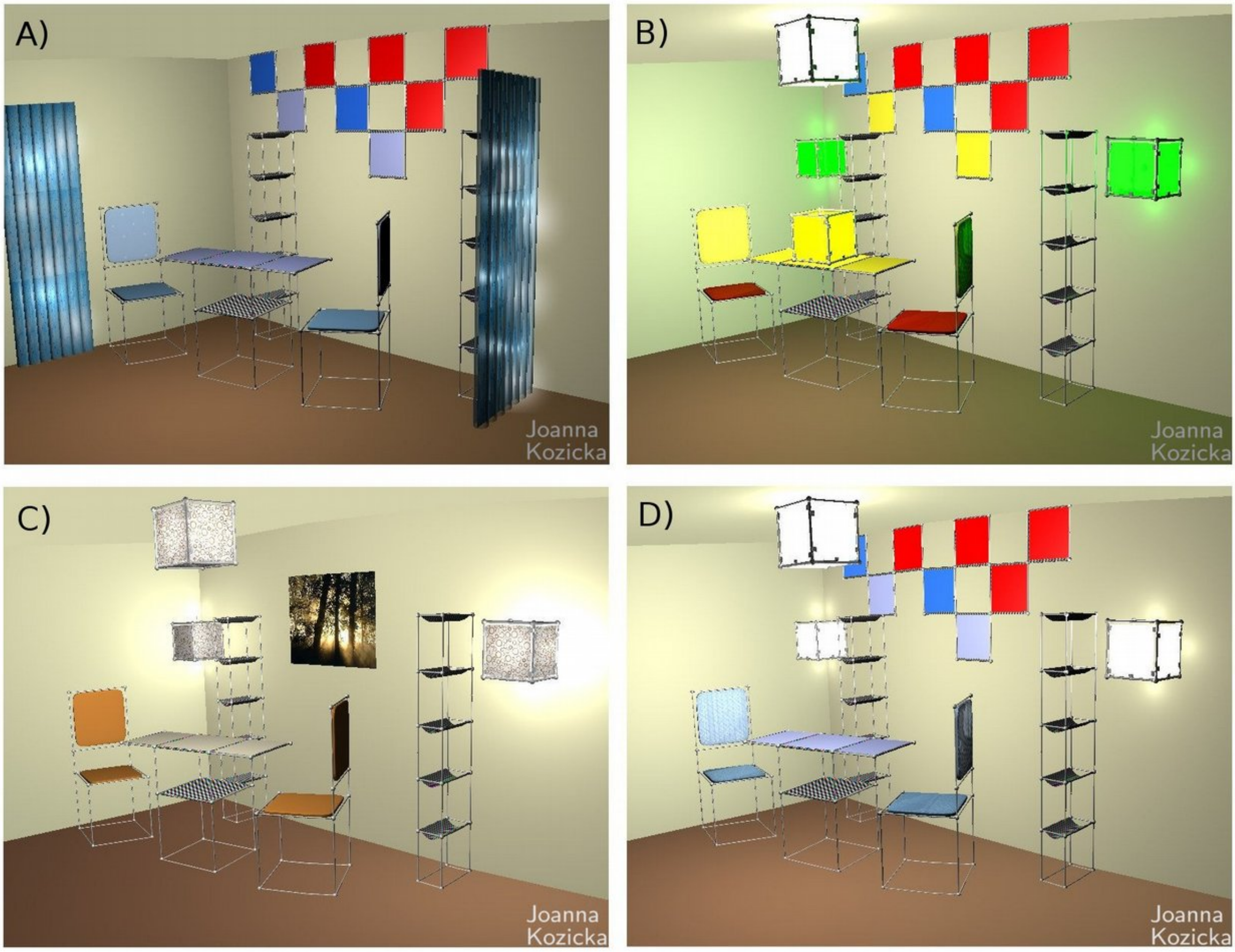
(d) Surfaces reflecting light may enlarge the illumination area, and create different light effects. There may be used metal and mirror elements, as: panels, sheets, 3D figures (Pict. 6.124) (Brownell 2006, p.211), concave or convex mirrors, mirror spheres etc. Small pieces of metal or mirror may be fixed to each other, or to fabrics, creating light and flexible decorating elements. They may be used as wall linings or cases for interior design elements. They should be used with caution, as they may create a dazzle effect.

(e) Liquid and frozen water can cooperate differently with illumination, e.g. it reflects light, or disperses it, creating interesting light effects. Drinking water tanks kept in Martian base, and waterworks system, may be covered with transparent cases. Waterworks could create small cascades, or even small waterfalls. Then, water would be illuminated, and appropriable elements would become a part of illumination and decoration system. Aquariums may also become illumination elements. There may be pigments added to water, and while dispersing—they would create fantastic, dynamic decorations, until they would give some color to water. Water could be also aired with air bubbles, creating good environment to grow plants in aquarium and to keep fish and corals in there. Light effects are shown in the Pict. 6.125 and 6.126 A).

(f) One of the easiest ways to introduce color into illumination of the insides is the use of transparent and clear elements tinged with different colors, illuminated from behind. A lamp may be shaded with a big wall panel, or a lampshade may have small removable panels, made from e.g. resin, fabric, foil. Such panels may be in various colors, decorated with pictures or patterns. In the Pict. 6.126 B, C and D there is an example of such a lamp shown. Panels may be clipped. Additionally, thanks to a simple form of a lamp, it may be put in various places in the room: suspended under the ceiling, hanged on the walls, put around on pieces of furniture and on the floor. Panels can additionally protect the eyes against a dazzle effect, especially when they are made from matte materials, e.g. frosted glass, transparent fabric. They disperse light and create an impression of illuminating panel instead of a direct source of lamp. They disperse light in the insides. Some of the materials can be used to write on with white-board markers, and to be colored with other means. Habitants of Martian base would try their drawing talents to express themselves. Additional possibilities to create light pictures may enhance their moods significantly and their psychological comfort. Illuminated panels would become safe for the eyes illumination sources and decorational elements, and they would function as information signs, notes, group's settlements (as tours for duty, a schedule of celebrations etc.).

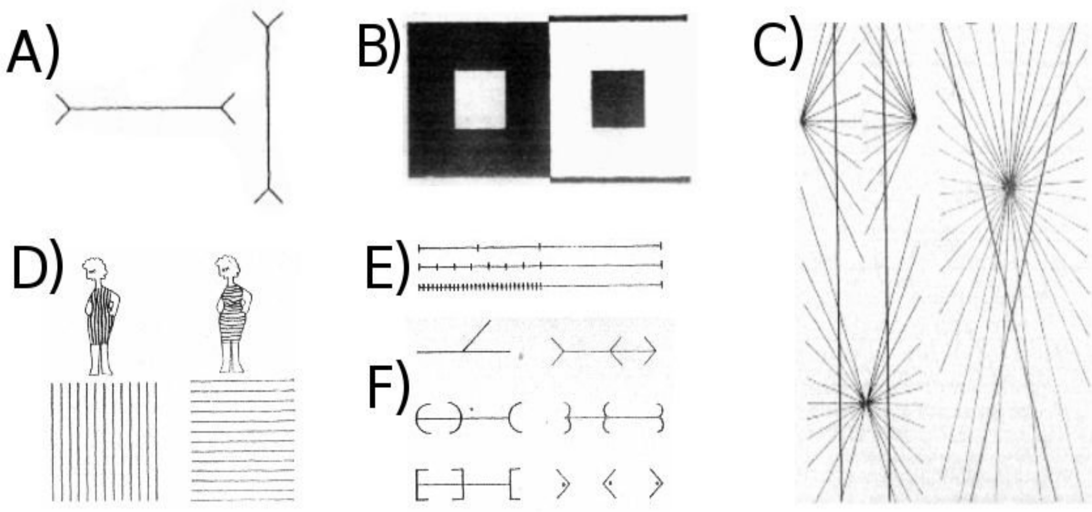
Picture 6.124: Split Block—ice sculpture (korbanflaubert.com)

Picture 6.125: Light effects in ice (icehotel.com)



Picture 6.126: Different ways of illumination of the same room : A) with panels covering water tanks, B,C,D) with simple lamps equipped with replaceable panels

Picture 6.127: The same room illuminated differently with LEDs (vossolutions.com)



Picture 6.128: Examples of optical illusions that may be used to shape architecture perception: A) vertical lines seems to be longer than horizontal ones, B) dark elements seems to be smaller than bright ones (irradiation effect), C) straight lines cut across with a bunch of rays seem to be curved (the Hering illusion), D) horizontal lines broaden, and vertical--elongate, E) among two line segments of the same length, the one cut across seems longer, F) identical line segments, the one with ends split outside seems longer to the one, whose ends are split to the inside (The Müller-Lyer illusion) (Mieszkowski 1975)

Modern illumination technologies give many opportunities to shape the space with light, and also economically and efficient. Light gives incredible possibilities to create mood inside a room, to create pretty flexible decorations, and influence strongly a user perception—their wellbeing, impressions, feelings (Pict. 6.127).

Depending on perception of specific kinds of illumination Martian base interiors, there may be listed positive and negative light effects. Negative light effects are: indirect dazzle effect (a strong contrast in the light), and direct dazzle effect (blinding light). For a specific example of Martian base, as an addition there would be a diminishing space effect, and all the others light effects that may induce negative feeling: antipathy, anxiety, fear, insecurity, loneliness, hostility etc.

With some help of introducing interior design elements, colors and illumination, there may be created different illusions. They would shape space perception. Optical illusions, which allow some influence on the architecture, are, among others, those elaborated by Mieszkowski (1975, p.38) (Pict. 6.128). Human eye can better judge width than height, that is why elements of the same length fixed vertically seem longer there the same elements fixed horizontally. Vertical elements cause perceiving a room higher, than it really is. Dark elements seem to be smaller than bright elements, thus, dark columns inside would seem lighter than bright ones. The Hering illusion painted on the walls may help to straighten optically the curves. Perceptional widening of the insides may be achieved by the use of horizontal divisions on the walls, instead of vertical ones, e.g. horizontally hanged shelves instead of high bookshelves. Additionally, dividing the shelves into segments can also make them look longer. Optical elongation of a shelf may create similar effect applying to the room, and introducing standing out elements at the ends of a shelf may support sufficiently the overall effect (The Mϋller-Lyer illusion).

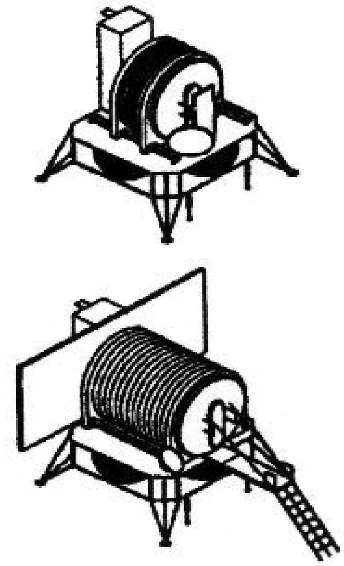
6.5 Example propositions of outer-space habitats

Exploitation and building settlements in the Space is one of the strongest human fascinations. There have been created many different futuristic visions of large Space habitats. Some of them were designed by engineers and architects, Architecture students—people, who have gained more or less of required knowledge to do so. Those concepts contain valuable clues and guides to the disposition of an architect of Martian base. As all previous Space habitats were small and tight for place, there have been researches conducted for years how to build them larger, with the possible minimum of financial expenses. Thanks to those researches there were designed many different architectonic concepts. The author gives here some of them to show the wide spectrum of inspiring solutions. An overview of Space architecture shows how many solutions there are to build a house in the Space. However, every solution has its advantages and disadvantages, and very often there are many questions left unanswered. Only some of the plans are treated with the utmost precision.

Small expandable modules

In NASA laboratories, in Johnson Space Center, 1996, there was designed a concept of an expandable harmonica-like module of the Moon spacecraft (Pict. 6.129). This is a construction of 2.3 m in diameter, and 3.7 m long (Cadogan and others 1999). The tip and the end of the module is made from metal elements. Between those two, there is a squeezed or stretched coating. Here, in this solution, there is created a large, however, monotonous, oblong space, where communication aisles occupy much of it, and it is difficult to divide into comfortable rooms.

Other solutions for small expandable habitats, to work and live in, for the needs of Space missions, have been created by Architecture students from several countries: France, England, Poland.



Picture 6.129: Expandable harmonica-like module of the Moon spacecraft (JSC NASA)

Picture 6.130: A concept of expandable Martian habitat by Soullard (planete- mars 2001)

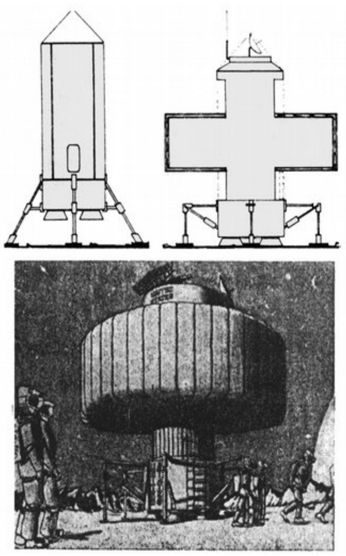
Soullard (Architecture student from France) suggested a standard metal module, fitting a launching rocket transport hatch (American design), to be constructed from four identical elements—quarters of a cylinder. They would be put together for the transportation to occupy minimum space. On the surface of the planet it would expand until it takes the form of a square, as it is shown in the Pict. 6.130. To finish the process, there would be four endings and an atrium created, coated with airtight pneumatic coats (planete-mars 2001). The author thinks that the whole installation of such a Hab would be very difficult on Mars. It would require a piece of really flat and smoothed piece of ground. There is left aside the question of pressure near the down edges and the floor of the habitat.

A group of students from **Northern Polytechnic School of Architecture** in London[17], England, had an idea to install a double coating to an oblong cylindrical module. The inside coating would be a rigid core, the outside coating would expand into a form of a plate around the core, in the middle of the core (Pict. 6.131). The outside coating, to reach its final shape, should stretch itself, so it has been designed to be made from expandable foam. It should get firm by itself after the whole process finishes, creating a firm structure (AD 1967b).

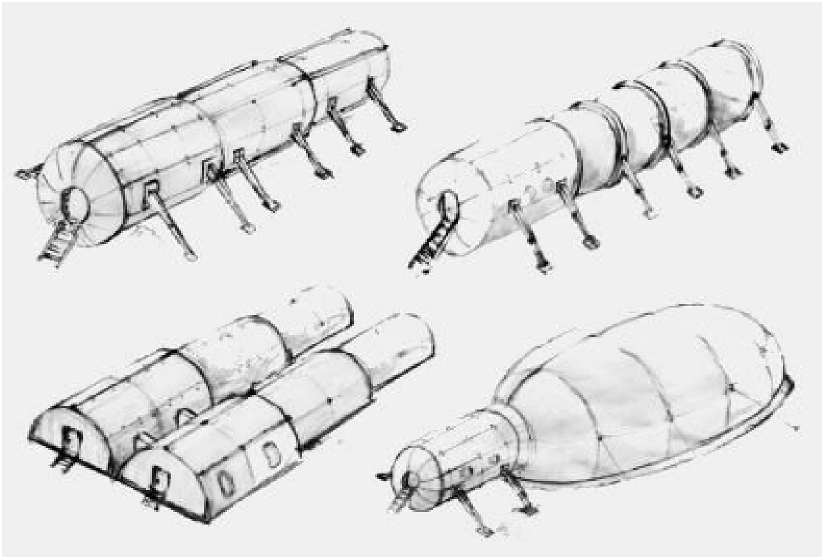
Kozicki (2004) gives several ideas. First, a Martian module may be built as a multilayer retractable telescope shell. Such a module may expand first into two

17 Members of the group of Architecture students: P. Ansell, J. Edwards, K. Hinshelwood, K. Lim, J. Smith and P. Wilson

halves of a cylinder, and they can expand later independently. This construction is stable and do not require special legs, but the pressure dispersion is less even. A cylinder may be made from rims connected with flexible coats. The more rims there are, the more space is created, and the longest the module becomes after expanding. However, it is monotonously oblong. At last, there could be attached to a module a pneumatic tent, which ensures larger habitable space and enables its diversification (Pict. 60132).



Picture 6.131: A concept of expandable Moon habitat by Ansell and others (AD 1967b)



Picture 6.132: Ideas of expandable Martian habitat by Kozicki (2004)

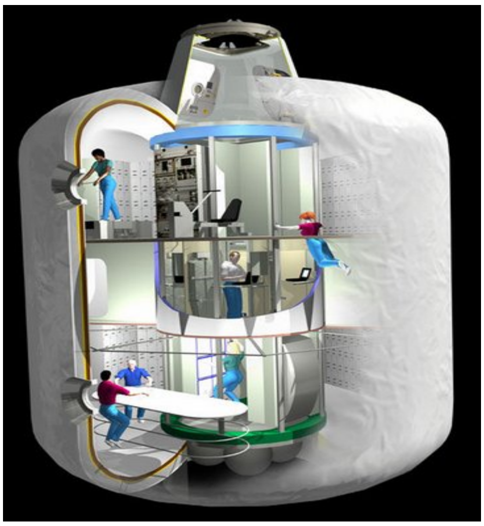
Nautilus Hotel

Nautilus Hotel is the first commercial satellite station, which is going to appear on the orbit of Earth. It will function as a Space Hotel. Nautilus construction is designed by NASA. It consists of the metal core, around which a pneumatic coating expands. It creates a habitat much larger than any of those launched from Earth until now. At the first stage a habitat is created by a single module (Pict. 6.133), which is later expanded with more, identical modules (Pict. 6.134). Metal, spherical modules, the same as there are used at ISS, will serve as connecting elements. Nautilus is equipped with a multi-layer coating, serving different functions: protection against gas leaks (polyethylene, nylon and EVOH); protection against micrometers collisions (nextel AF-10 partitioned with foam filling); ensuring mechanical durability (Kevlar); adequate thermal insulation (metal cover reflecting Sun-light); protection against Space radiation (polyethylene) (Cadogan and others 1999).

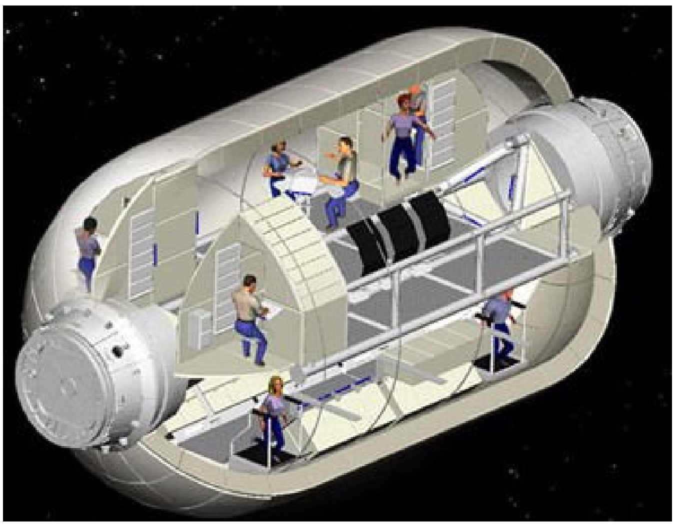
Nautilus has been created on the basis of the laboratory-inhabitable module design, TransHab, by Constance Adams. There are planned three floors in TransHab, vertically, in a cylinder 11 m long and 8.2 m in diameter (Pict. 6.135). There are a mess, a gallery and magazines on the ground floor, as well as public places for group meetings for the crew, and to dine together, spend their free time and meet after work. There are four cabins for the crew on the middle floor. They are very small, but still, it was possible to fit in a sleeping bag on the wall and a small desk wit a computer on it. Under the desk there are four hooks for legs to keep a stable position in the conditions without gravitation. The cabins were planned in the core, so they were without windows. On the top floor, there was a social room with sports and medical equipment. The floors separating each level were designed to be made from acoustic isolators and fire-proof materials (NASA 2003b). Natilus is 2.75 times larger then TransHab. The rooms are placed in the horizontally positioned cylinder, as it is shown in the Pict. 6.136.

Picture 6.133: The outside image of Nautilus (Bigelow Aerospace)

Picture 6.134: A hotel built from several Nautilus modules (Bigelow Aerospace)



Picture 6.135: A scheme idea of rooms-plan in TransHab (NASA)



Picture 6.136: A scheme idea of rooms-plan in Nautilus (Bigelow Aerospace)

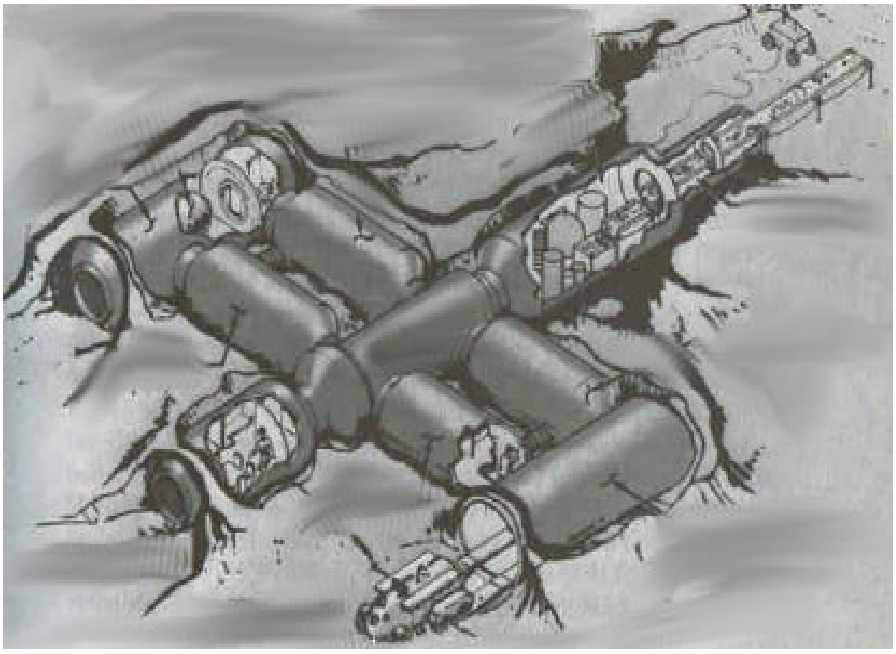
Space Island

Space Island Group (2006) designed a large, multi-modular orbital space. The modules should be connected at the orbit in a 3dimentional structure: a core and a ring around it (Pict. 6.137). There could be micro-gravitation conditions in the core. The base should spin around the core to create centrifugal force to function as artificial gravitation, to enable people to walk easily[18]. This base was designed to serve as a tourism-entertainment center. There would be the main hotel center in the ring, and several tourism attractions in the core, an art gallery, among others. Thanks to lack of gravitation, any directions would be allowed to admire the exposition of complete new art pieces (Space Island Group 2006). Elements for the base would be made from emptied rocket fuel tanks, the same as for the Space Shuttle[19]. Fuel tanks are considerably large: they are 47 m long and 22.5 m in diameter. They offer pretty large space to manage with, and its launching to the orbit does not create any extra cost, as it is a subsidiary waste. However, there are no windows, doors and inside divisions. Thus, to manage the interiors of those tanks creates several difficulties. The elements to manage interiors should be transported and fixed inside at the orbit. Instead of fuel tanks, there could be ready made working-living modules, similar to those that are made for Space habitats. Their transportation to the orbit would be much more expensive, but they would be made precisely to the plan on Earth, interior design elements included. One of the ideas of such orbital base is Berlin Hotel (Reichert 1999).

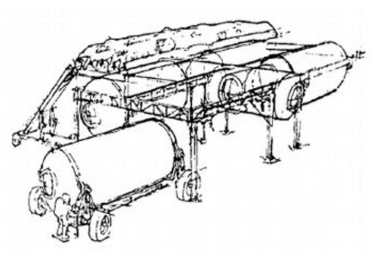
18The idea by Konstanty Ciolkowski, beginning of the 20th century

19The idea is taken from Kraft Ericke's solution. However, he suggested to gather the tanks into bunches (Wołczek i Thor 1958).

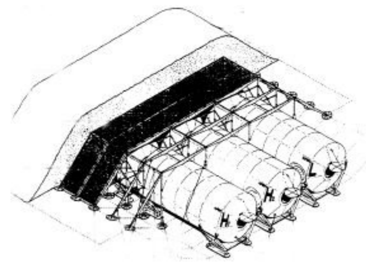
Picture 6.137: A concept picture of Space Island Group orbital base (Space Island Group 2006)



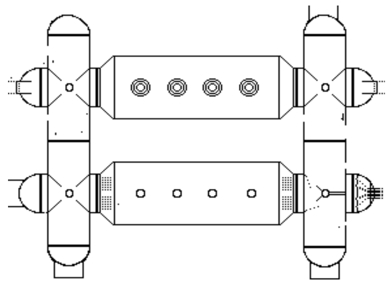
Picture 6.138: Oberg's concept (Dubbink 2001)



Picture 6.139: The concept of multi-modular Moon habitat by Griffin (Benaroya i in. 2002)



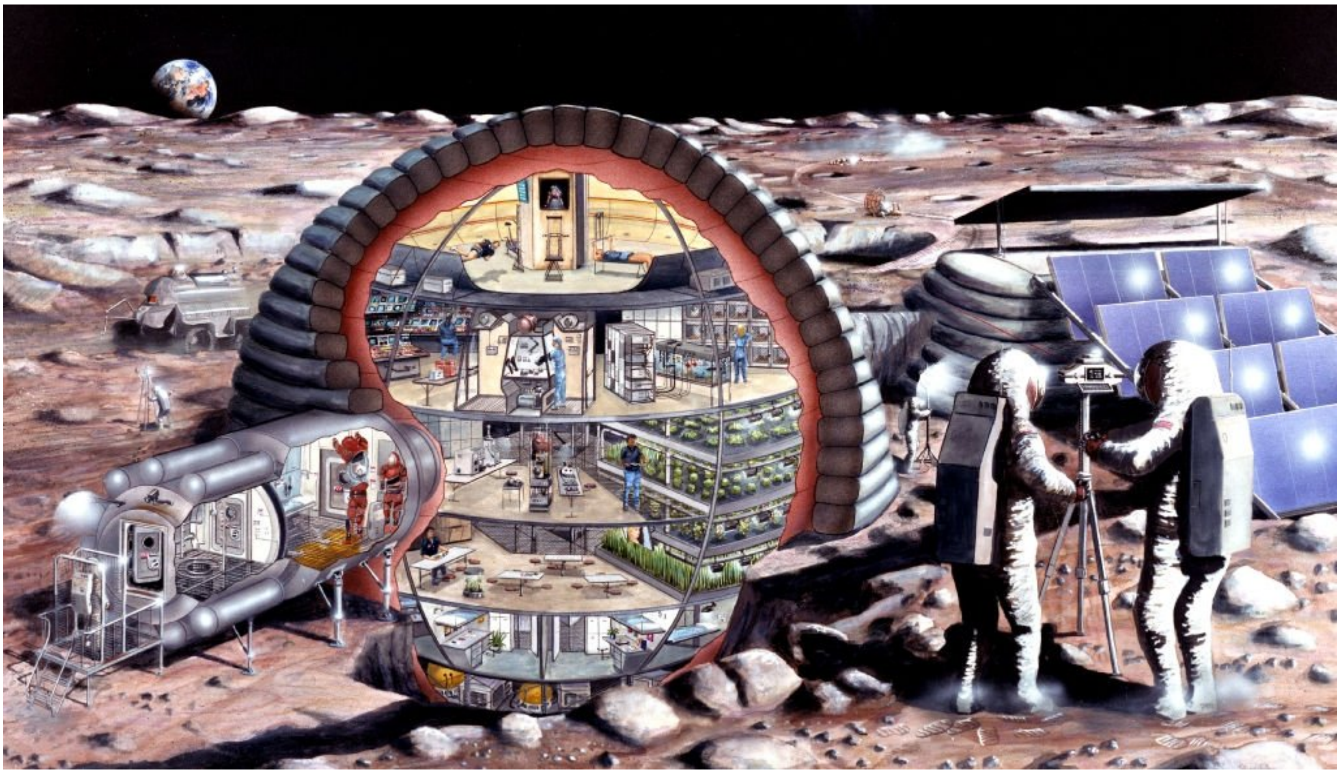
PIcture 6.140: The concept by Kaplicki (Ganapathi i in. 1993)



Picture 6.141: Multi-modular Space base based on Kokh's idea (Kokh 2002)

Oberg's Base

The base designed by James Oberg consists of a group of oblong, cylindrical modules, connected into a complex, as it is shown in the Picture 6.138. The ready base should be covered with the regolith *in situ* to be protected against mechanical damages, and against the Space and Sun radiation. There should be only entrances left uncovered, planned at the endings of some of the modules (Dubbink 2001). Thanks to their simple construction, the base may be extended with new, identical modules, connected to the existing ones in the same way. The metal construction of modules has been tested the most often in the outer-space, so it is the one, which seems now really reliable. However, the bulk mass of all of the elements would be huge, and building such a construction would be really expensive. There are similar solutions to find in literature, only slightly different from that one above: modules are put on scaffoldings (Pict. 6.139), modules are put into a hole in the ground and covered on the scaffolding (Pict. 6.140), cylindrical modules in two different sizes, capped with covers in the shape of hemispheres (Pict. 6.141).



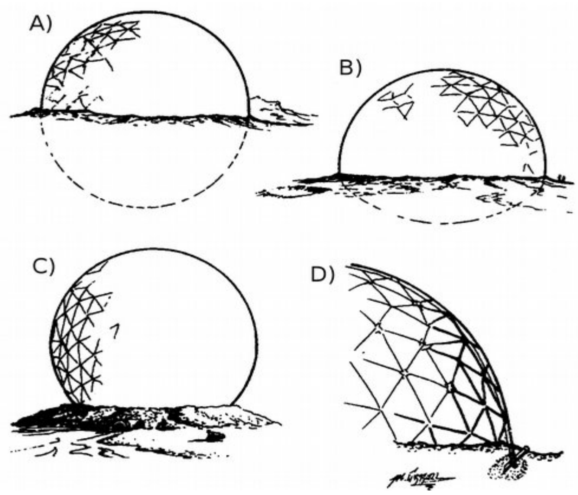
Picture 6.142: The concept of the Moon Base by Kennedy and Cerimele (JSC NASA)

Kennedy and Cerimele's Base

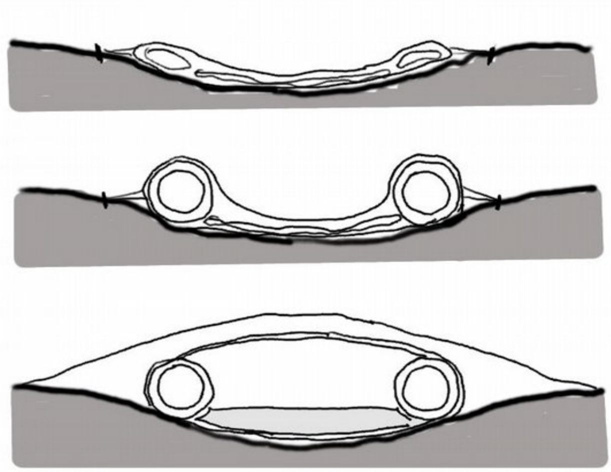
K. Kennedy and M. Cerimele designed in 1990 a moon-base in the shape of sphere (Pict. 6.142) (Ganapathi and others 1993, p.39). The sphere is large and spacious enough for several floors to fit in. It is partially settled in a prepared hole in the ground to stabilize the whole construction. The outside part is covered with bags filled with the ground to protect the construction against mechanical damages, and against the Space and Sun radiation. The sphere is connected with a cylindrical module with the airlock entrance. It is a frame-coated construction. Cameron and others (1990) conducted researches on the frame construction for a pneumatic Moon habitat. There were tested aluminum, titanium and reinforced polymers. According to their analyses, the best for the purpose is aluminum 7075 T73. The vertical and horizontal construction supporting were tested separately. There were vertical supporting tested: columns, trusses, flat truss systems, and expandable trusses. The analyses shown that truss systems and expandable trusses might the best solutions for the outer-space habitat. The structure was designed to be unfolded inside the pneumatic coating to abridge the time needed to finish the structure, and allow the crew to work without space suits. The truss system is light, its bulk mass is the lowest one among others that were tested. Aluminum alloy chosen to make the truss system is light and durable. The suggested solution allows creating a maximum manageable space with the designed mass. The authors think that such a type of construction would be used for a sphere, and for a cylinder, designed vertically or horizontally. Due to their suggestions, a spherical habitat should be partially earth-sheltered and supported with a foundation underneath. The metal skeleton creates here a reinforcing supporting for the habitat's floors, and for the vertical communication method connecting all the levels. Additionally, it ensures stability of the construction and its measurements.

Zubrin and Wagner (1997, p.240) described another solution for the construction. They suggest the pneumatic sphere as an independent reinforcement construction for the habitat, which rigidifies with atmosphere pumped into the construction. As the pressure inside the construction is much larger from the pressure around the habitat, there is no need to use any kind of pneumatic construction. It was calculated that there could be transported to Mars a dome of 50 m in diameter, which can fit a rocket hatch, without exceeding its maximum load. To protect the membrane on the outside, there could be attached supporting panels, made from plastic. Polycarbonate, which is durable and transparent, is suggested as the best one for the purpose, and it allows the sunlight to get inside the sphere. However, building such a sphere on the surface of another planet is very difficult, especially with such a large diameter. Even on Earth it requires a specially trained building crew (as it was in case of building Amundsen-Scott's polar base, see chapter 5.1.1).

There are four possible solutions to install the sphere (Pict. 6.143). There could be a deep hole dig out, the sphere put into it, and its lower part could be filled with pressed regolith, to create a hard floor (A). A membrane could be made from two pieces: the lower one would be a cut of a sphere of a larger diameter, to create an almost flat underside, which would require a shallow hole (B). The sphere could be balanced with an embankment in the shape of a ring around the dome (C). The last solution is to press the dome to the ground with a durable net, anchored to the ground on the perimeter (D).



Picture 6.143: Different methodologies to stabilize a pneumatic construction in the ground (Zubrin and Wagner 1997), description in the text



Picture 6.144: The way of unfolding and installation of a pneumatic, coated construction, according to the idea by Chow and Lee (Benaroya and others 2002)

Chow and Lee's Base

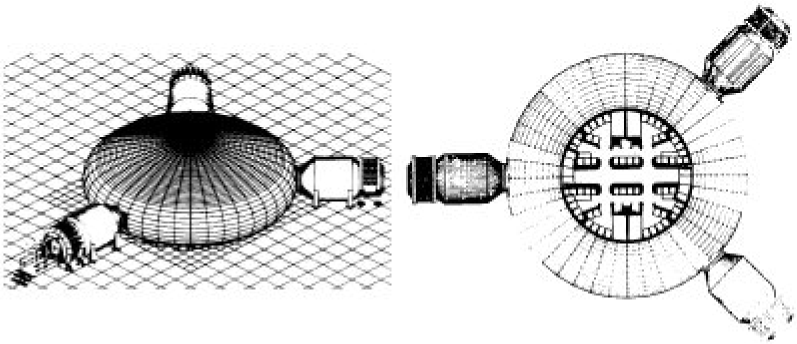
There are at least several concepts of outer-space bases, which exploit pneumatic structures in the torus shape, with the airtight circle inside. Such a structure consists usually of a circular rim, which is made airtight with an underside and a top coating. P. Chow and T. Lee worked out the installation plan for such construction. First, the whole construction is unfolded and anchored in the ground on the perimeter. Next, the torus ring is pumped up, which contains usually the circular communication duct, airlocks and the maintenance of the habitat. After that, the center of the torus is pumped up, and the underside part is covered with the ground, pressed flat to make a flat floor (Pict. 6.144). Additionally, the whole habitat may be covered with a layer of the ground to press down the stretched construction, and to protect it from the radiation (Benaroya and others 2002).

A similar concept, with an additional functional design of the insides, present Huebner-Moths and others (1993). Here, three metal exit airlocks are attached to the torus from the outside. The pneumatic ring is occupied by laboratories, monitoring and technical rooms. The center of the torus is divided into two floors. The down floor is planned for the living zone, and there are private cabins and bathrooms. The upper level is planned for the recreating area with the gym, the mess, the library and the recreational part. The concept is shown in the Pict. 6.145.

PAX Plan

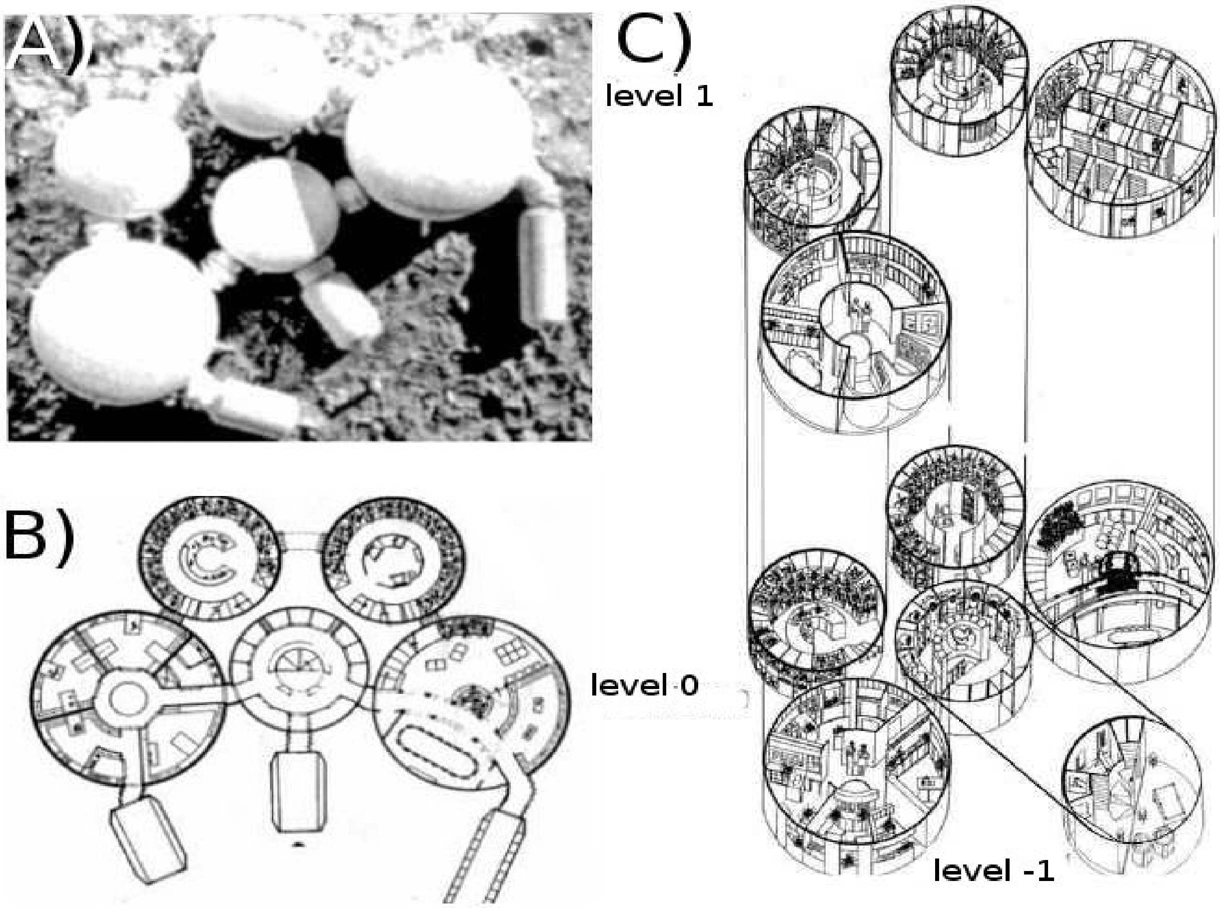
PAX plan, i.e. Permanent Martian Base, has been designed by Gary Moore in 1992 (Dubbink 2001, p.89). It is a complex consisting of five domes. Three of them are smaller (9 m in diameter), and two are larger (12 m in diameter). The three smaller domes, without any justification to find in the literature sources, are prefabricated firm modules, and the two larger are pneumatic structures. There is a steel frame fixed above the firm modules, to keep the protective layer of regolith. Thus, none of the elements of base needs to transport any additional encumbrance. As it is so, all of the domes could be pneumatic constructions (and cheaper for transportation).

All of the elements of the base are divided into two floors. A central module of the complex functions as the main entrance into the habitat and there is also a changing room where space suits are kept, and there is also an exit to the surface preparation chamber. The author points that this changing room is too spacious, as there are large space suits for astronauts shown, and not those more comfortable Martian suits, as e.g. Marcey and others (2004) suggest. It is also a little odd, even if not careless, that there are planned places to store space suits for one half of the crew only. However, there are three such places designed altogether. There are two small elements planned in the back of the complex, housing greenhouses. There is a living area, with private cabins, planned on the first floor, alongside with the recreational area on the ground floor. The second dome contains laboratories (Pict. 6.146). Howvere, a problem of curves in the design is neglected here, and for both the floors there is considered the same living area planned. The living area is planned in one of the large modules, where the ground floor is designed for recreation. The stairs lead up to the level designated for private quarters, and there are laboratories in the second large dome, which can be reached by a small module, containing a preparation chamber for EVA. Theoretically, the other two modules are connected to the complex with airlocks. It is difficult to find communication ducts for this purpose in the projection. It also lacks documentation for the partition of the modules: no plans of horizontal divisions (ceilings), or vertical divisions (walls).

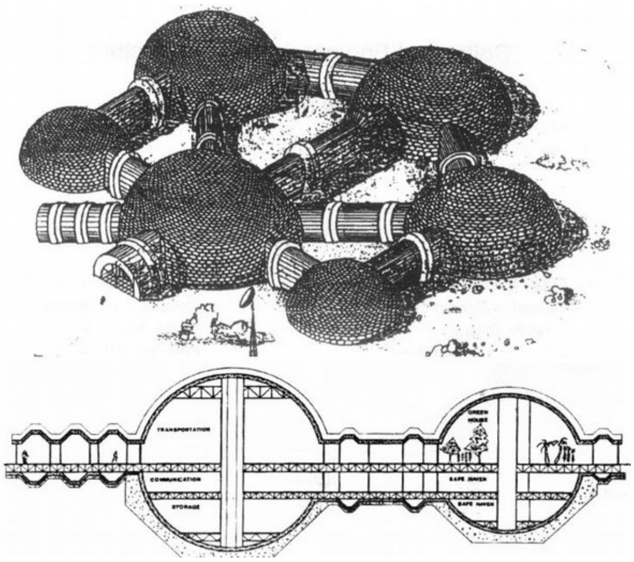


Picture 6.145: The concept for pneumatic base by Huebner-Moths and others (1993)

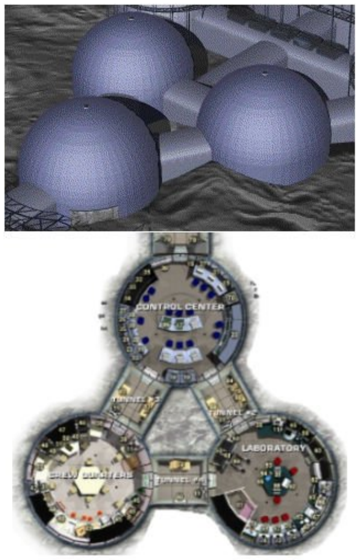
However, the problem of the crew's psychical comfort is tackled professionally by the author of the project. The division into zones is achieved with the separation into functions in modules. It may prevent any conflicting neighborhood, e.g.: working areas are separated from recreational areas, loud—from silent, well-lit—from darker. Every module has its own specific interior design, what breaks the monotony of confined environment, and supports the orientation in the whole complex. Communication scheme enables the crew to move around the base easily, and ensures a safe evacuation way from each point of the base. The architect elaborated the color design, the light sources and interior design to maximize the psychical comfort of the crew. There are to work and live eighteen Marsonauts in this five-element, comfortable habitat. The detailed plan of separating functions, and arrangement of the habitable space in the base are shown in the Picture 6.146.



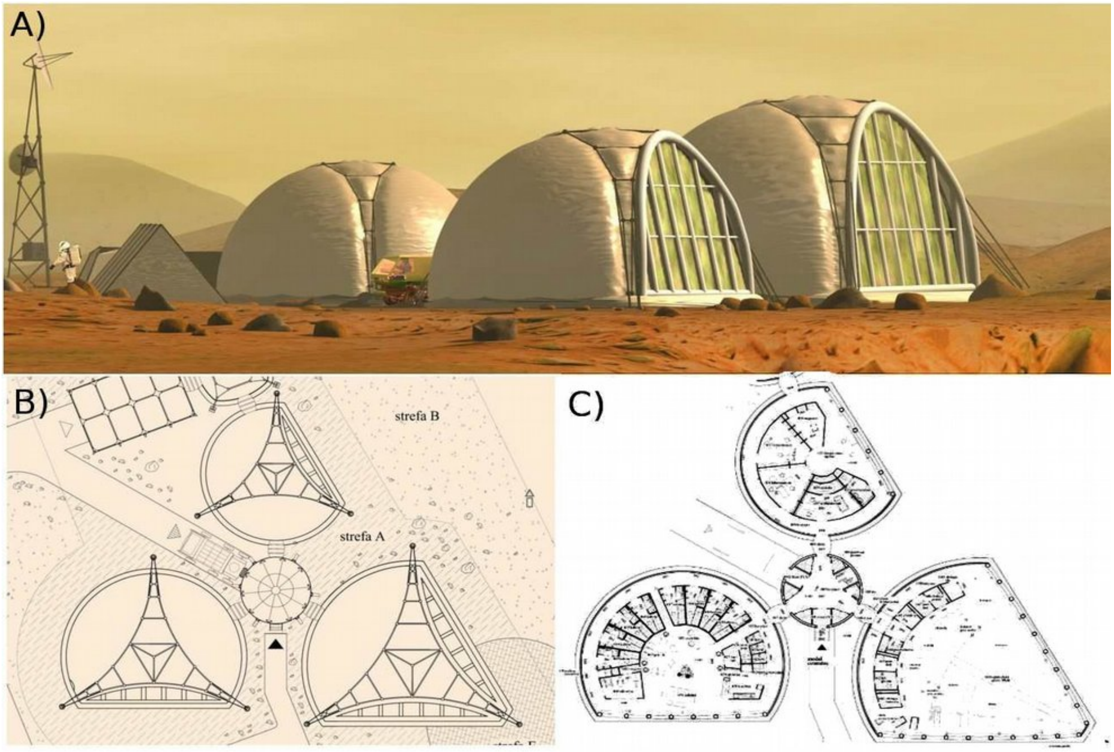
Picture 6.146: PAX concept of Martian base by Moor: A) a model, B) a horizontal projection, C) a plan of functions in axonometry (Dubbink 2001) [poziom 1—level 1; poziom 0—level 0].



Picture 6.147: A plan of Martian base by Hexa- mars: axonometry of the whole, cross-section (Sabouni and others 1991)



Picture 6.148: A concept of Martian base under domes by Bio- BLAST group, (www.cet.edu/products/bioblast/preview.html)



Picture 6.149: A concept of a Martian habitat: A) facade, B) situation plan, C) horizontal projection (Kozicki 2004)

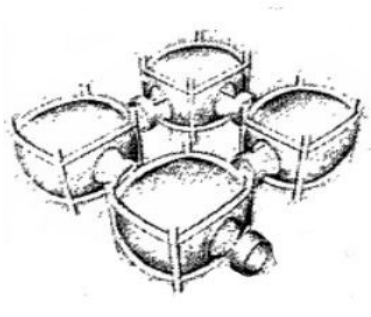
There are also other concepts of complexes of domes, e.g. Hexamars (Pict. 6.147), Bio- BLAST (Pict. 6.148). There are broad, planned for different functions tunnels connecting the domes instead of airlocks. However, there are also several inconsistencies in those projects.

Professional Research of Station on Mars by Kozicki

There is a very interesting concept of three pneumatic domes with window elements, with a pneumatic framing, designed by Kozicki (2004). The domes are connected with a central metal module, equipped with entrance airlocks to the surface, a safe shelter for the Sun storms time, surrounded with water tanks. Every dome is in different size, what agrees with their different functions: one is planned for the living function, another one—for laboratories, and there is agriculture in the third one. Most of the coatings of each dome is made from exceptionally durable weaved Kevlar and obturating polyimide membrane. Windows are planted into fragments of domes to achieve large transparent surfaces, giving a good illumination for the insides (Pict. 6.149). Because there was no possibility to use here much more durable membranes, a frame construction assures safety for the window elements. Laboratory and living chambers are equipped with pneumatic walls, reinforced with pneumatic girders, where a pressure is slightly higher. They are connected with each other, with floors and ceilings suspended with zippers. The obturating system imitates the one used in Russian space-suits.

Base in Pneumatic Cubes by Sadeh and Criswell

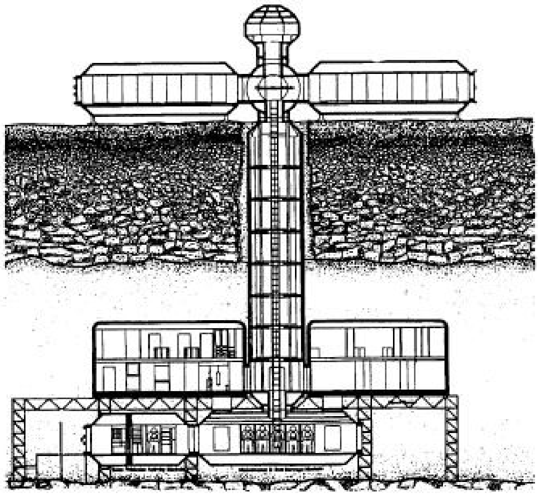
Streamlined forms allow the pressure of artificial atmosphere inside to disperse evenly in an outer-space habitat. However, they create some difficulties in standardizing the way of the interior management, and they are very far-fetched from the image of a common house in a rectangular projection. Willy Sadeh and Martin Criswell are the authors of the concept which answers those expectations. They suggest building an additional reinforcement to make firm a spherical pneumatic structure. Such firming causes a module to achieve a cube-like shape. Such element is light, easy to fit, and allows connecting with identical modules into a group or a larger complex. Such a system of repetitive construction enables building a base in any imaginable spatial configuration and a free expansion of a habitat. Modules and their connecting is shown in the Pict. 6.150. It was suggested to cover the habitat with bags filled with ground, to isolate It better from the outside conditions (Sadeh and Criswell 1996), (Sadeh and Criswell 2000).



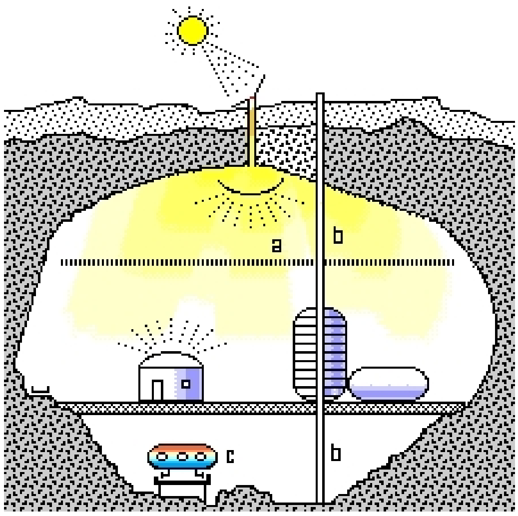
Picture 6.150: The concept of pneumatic framed modules (Sadeh and Criswell 1996), (Sadeh and Criswell 2000)

Moor's Base in a Lava Tunnel

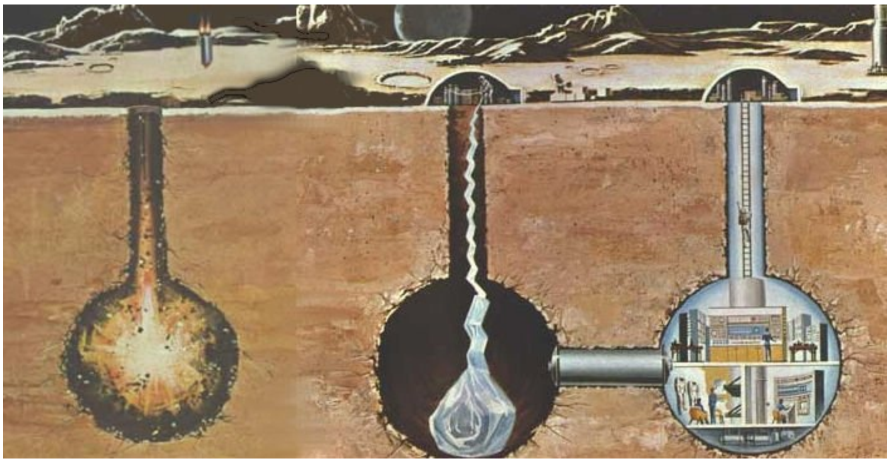
G. Moore designed a base in a lava tunnel. He suggests earth-sheltered metal modules on a scaffolding inside a lava tunnel (Pict. 6.151). Modules would be made from a double layer of weaved Kevlar and an obturating membrane fitted between them. The construction is positioned close to the entrance to give people a view from the windows on the scenery nearby, and to allow the partial sun-light to get into the insides. The main part of base is available via a vertical tunnel drilled in the rock-mass. On the top of this tunnel there is planned a preparation chamber before going outside and before entering the airlock. This part is covered with a special protection coating against radiation. Its efficiency seems to be significantly lower than it would be in case of a habitat earth-sheltered completely (Ganapathi and others 1993, p.43). Here, the concept of an underground habitat gives a good protection against radiation, mechanical damages and weather conditions. However, a durable construction should be built and tested. Thus, it does not give any economical profits.



Picture 6.151: A concept of the habitat in a lava cave on the Moon, based on the idea by Moore (Ganapathi i in. 1993)



Picture 6.152: A concept of the habitat inside an outer-space lava tunnel, based on the idea by Kokh (2002)

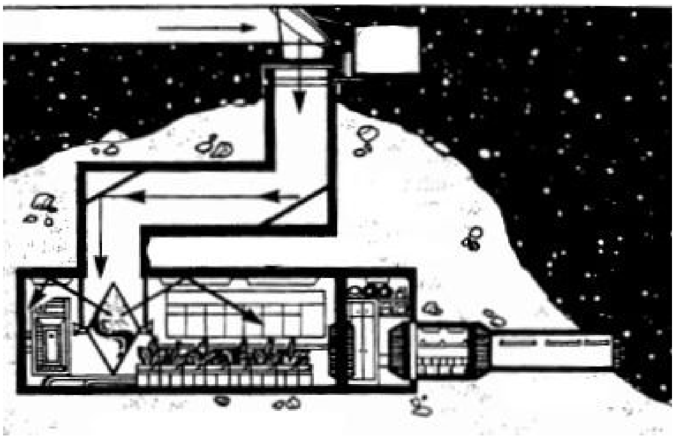


Picture 6.153: A concept of the underground habitat presented by Cole i Scarfo (1965)

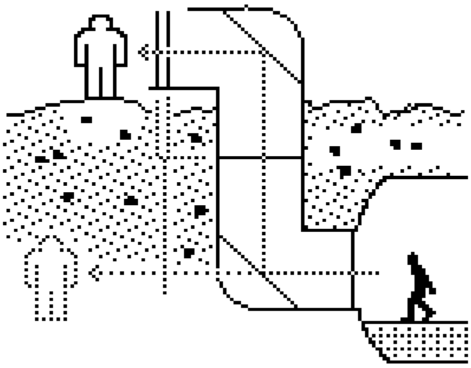
Peter Kokh (2002) presented a precise idea of managing the fragment of a lava cave. Its walls function as walls of the habitat. There is a huge area to manage with, which should be obturated only at its ends. Cooperating mirrors illuminate the habitat: a mirror on the surface faces the Sun to focus its rays, and directs them into a small shaft. Light directed that way next is reflected by another mirror, and is dispersed in the lava tunnel (Pict. 6.152).

Underground Base by Cole and Scarfo

Cole and Scarfo (1965, p.71) present a concept of the spherical, underground habitat (Pict. 6.152). An opening inside the rock-mass is done with a detonation of explosives put at the bottom of the shaft prepared in advance. A spherical cave is obturated with a pneumatic coating, and later it is equipped with all the required things. A vertical shaft leads to the surface part of the habitat with the observation dome. There could be created several similar caves, connected with each other with underground tunnels.

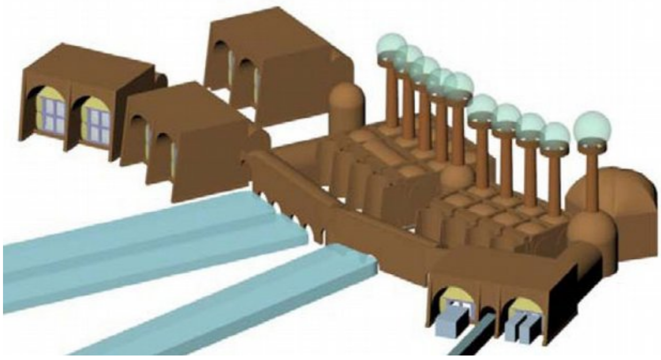


Picture 6.154: A drilled Moon-base illuminated by the system of mirrors working as periscopes, based on idea by Burke (Ganapathi i in. 1993)



Picture 6.155: A periscope window suggested for an outer-space underground habitat by Kokh (2002)

Picture 6.156: A concept of a Martian habitat drilled in an ice block (R&Sie 2002)

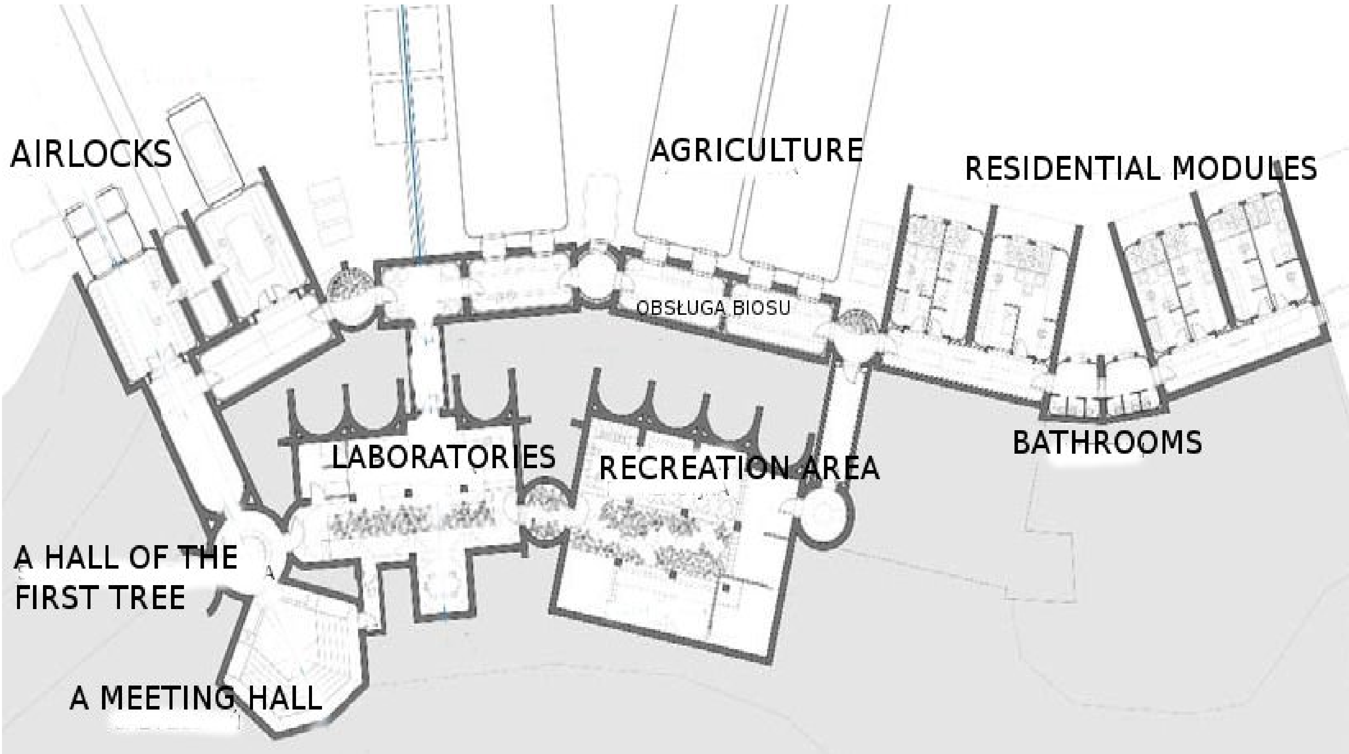


PIcture 6.157: A concept of the layed with stone Martian habitat by Petrova, axonometry (Petrov 2004)

This base is without any windows and out of reach of the sunlight. There are, however, solutions to solve the problem. J. Burke suggests an earth-sheltered habitat to be built inside a drilled cave. It is settled in a hill surrounding a crater on the Moon. There is the highest chance to find large water supplies in such a place, and the sunlight should reach the habitat there via an orbital mirror. Such focused light would be directed into the habitat's tunnel reflected by the system of mirrors working as periscopes (Pict. 6.154). Kokh (2002) suggests the same solution to illuminate the insides of Martian base, and to build windows as well (Pict. 6.155).

Ice Base by R&Sie

R&Sie Group (2002) presents a structure drilled in a large block of ice. Authors exploited the possibility of creating softly curved lines, oblong—for the design of interiors. Tunnels and caves are irregular in size and shape (Pict. 6.156).

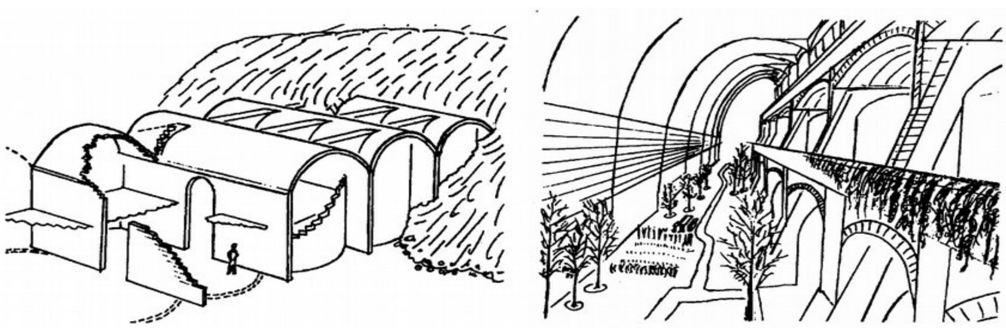


Picture 6.158: A horizontal projection of the habitat (Petrov 2004)

A Layed with Brick-Stone Martian Base by Petrov

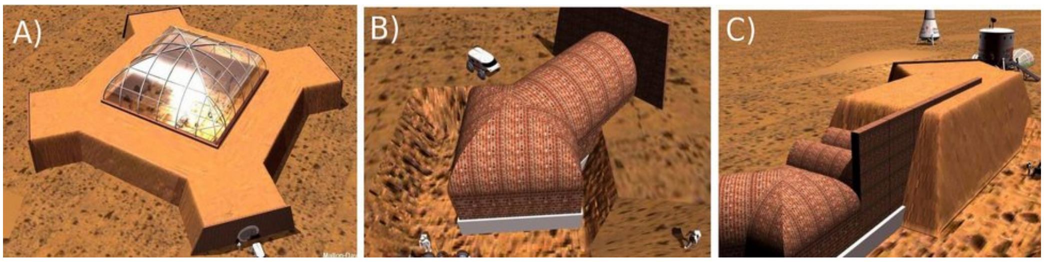
A base by Georgij Petrov on Mars is layed with stone, ceilings vaulted, and there are domes supported on pillars in more spacious chambers (Pict. 6.157). Layed with stone buildings are connected together into one, large complex at the foot of a hill, where a part of the habitat is sheltered. Rooms at the outside perimeter of the base have openings for the view of the landscape around. The rooms in the hill have purpose-designed skylights. Vertical shafts are layed with stone to the surface of the hill, where there are mirrors covered with transparent domes to focus and direct the sunlight into the habitat underneath. The base is large, divided into zones, each of a completely different, unique character. There is a separate building for laboratories. Its horizontal projection is the one the most complex. A spacious column chamber is for the recreational area. The residential zone is planned aside, to be left in a silent area. Thus, as it is seen, the human aspect is taken here in careful consideration: the base character is diversified in nature of places, conflicting functions are separated, illumination is natural sunlight, and there is a view for the landscape from private cabins. There are designed two additional chambers of a strong, unique nature: a meeting hall, and the place for the first tree planted on Mars. There is a lot of green in the habitat, both in working and in recreational area. Every private cabin has a place for a private garden. One disadvantage of the project is a very complicated communication plan: evacuation way is much too difficult to reach, especially from residential area. The plan of buildings is irregular (Pict. 6.158). It is dictated by the shape of a hill, at the foot of which the base is planned. However, following precisely the plan may be exceptionally difficult in Martian conditions to build the base. On the other side, as the buildings are layed with very small bricks, some flexibility in fitting buildings to each other is assured. Additionally, Petrov assumes, the layed with brick-stones base is connected with residential modules of several first manned missions sent to Mars according to NASA DRM program. The construction of the tunnel is not shown in the plans by Petrov. It seems uneconomical to build such a tunnel, especially when LSS equipment is to work there, too.

Picture 6.159: A plan of the residential module by Petrov (2004)

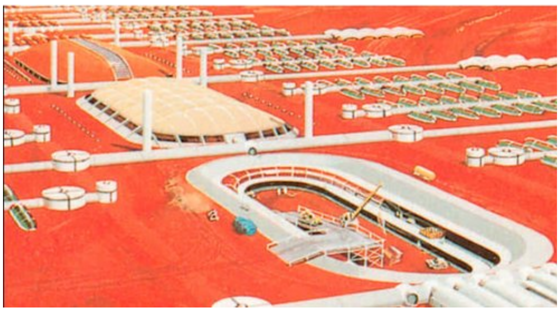


Picture 6.160: A concept of layed with brick-stone, underground chambers by MacKenzie (Zubrin and Wagner 1997)

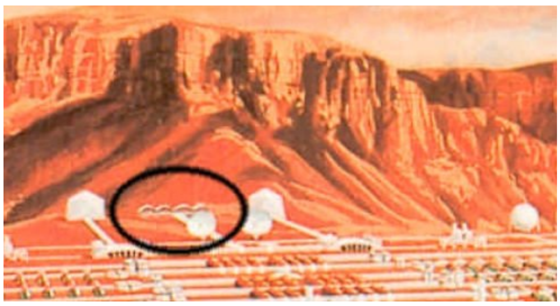
The agriculture area is planned in oblong modules, designed perpendicularly to the hill. They are connected with maintenance rooms and magazines. Some of the rooms in the base are layed with stone only, and some are additionally obturated with a membrane. As the author here points out, those layed with stone only are of more complex form, with columns inside. At the same time those are the ones hidden in the hill, where obturation is achieved with the layer of ground. It should be also pointed out that obturated that way parts have slightly different cross-section, and construction works there in a different way. Residential chambers are the example of obturated ones. A single module is fitted in a layed with brick-stone tunnel, on the layed with stone platform. Such a module is not adjacent to the walls of this tunnel. A whole segment is constructed from a simple, metal frame, inside which a pneumatic, air-tight membrane is pumped in (Pict. 6.159). A frame is made from facing each other shields with holes in them, into which there are installed windows and doors. There is a reinforcing construction to keep the walls and ceilings, suspended between those shields. The walls and ceilings are to be built from designed for the purpose panels. The elements dividing the space may be fitted in different configurations. Thanks to this, in one two-storey module there could be created different types of rooms: single rooms for one person, or rooms for couples: the rooms may be connected on one floor, or on two floors—with stairs, to create a room with an entresol. A single-room is rectangular, oblong, and considerably narrow. A way of suspending the pneumatic membrane onto the frame is not precisely described. It shapes the walls and obturate the module. The part adjacent to a window is a good place to make a private garden. Some green in a room would surely enhance the mood of residents, and would keep the artificial atmosphere inside well oxidized.



Picture 6.161: A concept of the layed with brick-stone Martian base by MarsHome Group: A) a view, B) i C) building stages (marshome.org)



Picture 6.162: Pneumatic modules with terrariums according to the design by Mars Habitation 2057 (Dubbink 2001)



Picture 6.163: The entrance to the underground residential part of the base Mars Habitation 2057 (Dubbink 2001)

MacKenzie was the first one who suggested exploitation of laying with brick-stone (1989). In his architectonic concept he suggested building adjacent on the sides to vaulted tunnels. As they should be earth-sheltered in deep holes, and covered with a thick layer of ground, they would seem as those built on Earth (Pict. 6.160) (Zubrin and Wagner 1997).

MarsHome Group presents a concept of a surface habitat layed with stone, with an inside atrium covered with clear roof. Layed with stone parts of the construction are covered with ground. The Pict. 6.161 shows the stages of building it, the final construction, and a view from the atrium's level into the vaulted, layed with stone, tunnels (marshome.org).

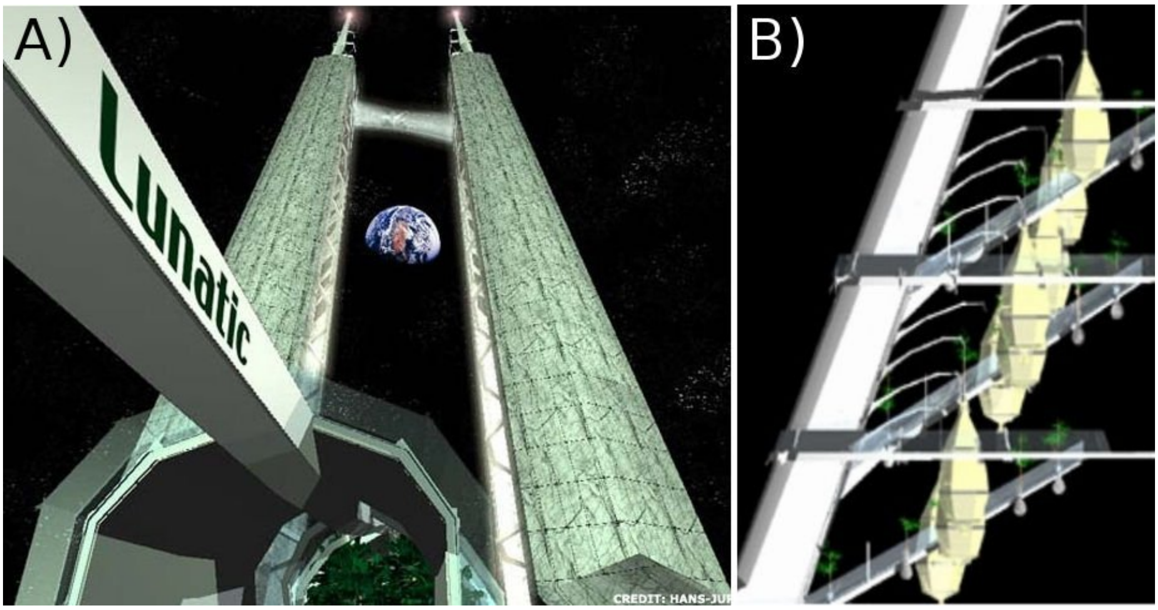
Mars Habitation 2057

Mars Habitation 2057 is a program of building a base on Mars. It was designed by a private company Obayashi Corporation in Japan, in 1990. A Martian base, according to their plan, is to be a self-sufficient habitat unit. It is planned for 150 people living there permanently, including: pilots, engineers, scientists, doctors, psychologists, journalists, artists, chefs and the captain. Apart from that, this base should be available for 150 tourists at one time. There is a valley, surrounded on three sides with hills, chosen as the site for the base. The hills are supposed to shelter the base and protect it from the pressure changes, and from the winds. There should be available hoarfrost to be collected on the slopes, to elicit water from it. Three zones of buildings, together create the whole complex: residential, agricultural and terrarium zones. Is is assumed here that habitats should be drilled in the slopes of hills, where they would be protected against radiation pollution (Pict. 6.162). The agriculture should be created by the net of small gardens in plastic cylindrical modules, 15 m long and 5 m in diameter. They are half-filled with ground, to stabilize an element on the surface, and to assure soil for growing plants. The whole zone should occupy the area 15.400 m^2. There are planned terrariums in close vicinity of greenhouses, in a form of large, pneumatic domes housing artificial ecosystems (Pict. 6.163). The plants growing there are to gather carbon-dioxide from Martian atmosphere and process it into oxygen. The moment the atmosphere is properly oxidized, the dome would be additionally obturated and covered with the layer of ground to protect it from the radiation. Starting that moment, the mirrors system would illuminate the place, where animals and insects would be bred. The pneumatic dome is planned on the ring-like construction, covered with protecting layer of ground. When ecosystem works properly, as planned, the perimeters will be ready for the residents, with a view at the green landscape (Dubbink 2001, p.85). The complex is large, and its building would require much financial expenses.

Hilton Hotel on the Moon

Hilton Hotel on the Moon was designed by a Dutch architect, Hans Rombaut, contracted with Hilton Syndicate. The habitat is created by two towers, 160 m high (Pict. 6.164). They are connected by a large entrance hall on the ground floor, and by a small bridge in the middle of their height. There are guest rooms planned in the towers, to entertain two hundred visitors, and there are designed vertical communication ducts. The rooms are planned to have two floors each, suspended in tear-shaped modules. (Pict. 6.164).

The hotel maintenance crew would be occupying an underground part of the habitat, two hundred of people, where they would be protected from the Space and Sun radiation. There is planned at the entrance a Moon Pub, three restaurants, amusement arcade, and gyms. The walls of the towers have a double-layer structure. The outside layer is made from the rocks acquired *in situ*, 18 cm thick. The inside water layer, 35 cm thick, would be a very good protection from radiation. Thick walls of the habitat are very light in the Moon environment. The towers are slightly slanted, what creates difficulties while building the construction, and later—to keep it stable. The water layer, according to the plan, is to be created by glass surface-layers. It seems really complicated to build it. 35 cm of water for both of the towers would consume large quantities of this material, which is rare on the Moon. Processing it there would take much time. Thermal isolation is not described in the project, and in what state water would be kept in the glass walls. Covering towers with rock-layer seems as a very good plan, as it would ensure durability of the walls, and a very good protection against micro-meteors, but at the same time it shuts the whole habitat from the sunlight. The insides would be illuminated with artificial sources of light only. The Earth and the Sky would be seen from the ground floor exclusively—from the area surrounding the entrance hall.



Picture 6.164: Hilton Hotel on the Moon: A) the outside view, B) tear-shaped hotel rooms (Jurgen Rombaut)

Conclusions for architect

There are many different architectonic concepts of outer-space bases. They may be an inspiration for the architect of Martian base. They are not *projects sensu stricto*, but rather the suggestions they contain are real food for thought. Many of shown there construction, function and form solutions are really interesting. The analyses of different projects led the author to create a list of constructive conclusions.

1. There are known technologies that are available to be adapted on Mars. The concepts of outer-space architecture show that those technologies may be exploited in different ways to create habitats in different forms. Until now, the Space architecture science is a real gold mine inspiration for an architect of Martian base.

2. Due to low gravitation, a deadweight of Martian constructions may be smaller. There may be designed large, massive buildings (as Rombaut suggests). However, the constructions must be stabilized in the ground very thoroughly. It is possible to achieve with pressed ballasts (as Petrov suggests), good anchorage (as Zubrin's frame constructions of the domes) (Kozicka 2004b), or with partial earth-sheltering (as Cameron and others suggest).

3. To protect outer-space habitats against the Space and Sun radiation there is regolith gathered *in situ* suggested in most cases; the constructions are covered with the regolith or bags filled with it, and they are put in layers. The former solution is suggested for layed with brick-stone constructions, which require ballasting to tighten the structure; the latter solution is the most effective for cylindrical constructions elevated on legs. The easiest habitats to cover with regolith are those earth-sheltered in underground tunnels, e.g. in a lava cave. Water may be used to build an anti-radiation layer, as it is shown in the Rombaut's Hilton Hotel project. However, stable divisions made such way are still to be thought of carefully.

4. A large and dependable Martian base may be built from one-element metal modules connected together. At the same time it a very expensive solution. To lower the expenses it is worth considering connected expandable modules.

5. Large habitable area may be assured economically in Martian base with the help of: expandable constructions, unfolded constructions, or with the use of natural resources *in situ* and the diversity of Martian terrain.

6. The idea of creating a special kind of hall in Martian habitat, like the Hall of the First Tree seems to be a very valuable one in Petrov's concept (2004), or another one—an exceptional form of a specific place—as a Meeting Hall in the same project. It would enable the residents to get used to the new place, to make it more than just a shelter and place of work, but a habitat, a specific environment to live in, with its characteristic, and ability to integrate the community there.

7. Windows and natural illumination influence positively people living in outer-space habitats. This influence was spotted very early at those habitats.

Additionally, natural sunlight helps to save energy (Kozicka 2004). That is why it is suggested to plan windows at least in private cabins and in the public places, e.g. in messes. Underground habitats should have special openings (e.g. an entrance to an ice cave as in Moore's concept), skylights (as in Petrov's concept), or periscope windows (as in the concept by Burle and Kokh).

8. Lava caves on Mars are probably large enough to provide spacious, flexible habitable area to manage. Illumination and obturation of such caves is the problem which requires to be taken into consideration.
9. Habitats may be drilled in a rock-mass (as Cole and Scarfo, and Burle suggest), or in an ice-block (as R&Sie suggests).
10. Pneumatic constructions form themselves into sphere, cylinder, and torus. To achieve the largest possible manageable area inside a pneumatic structure there could be applied different solutions:
    - building a multi-level construction inside e.g. a large sphere (as Kennedy and Cerimele suggest)
    - designing many multi-modular pneumatic structures joined together into a complex (as Sabouni and others suggest)
    - planning a large torus and obturating the inside part (as Chow and Lee suggest)
    - tightening coating pneumatic elements with a pneumatic frame into more functional shape of modules (as Sadeh and others suggest).
11. Plants may be grown to process Martian atmosphere into oxidized atmosphere, without using any energy-consuming equipment, to create more and more usable area for live creatures (as Obayashi suggests). Small green gardens may keep the level of oxygen on a good level in private cabins (as Petrov suggests). The author here points out that plants may pollute the atmosphere with germs and organic radicals of mildew and fungi, so their straightforward introduction into the insides of habitat should be thoroughly analyzed on the side of the safety precautions.

7 Architectonic Models of Martian Base

On the basis of conclusions for architect elaborated in previous chapters of the dissertation the author created different models of Martian base. There are shown several concepts to prove that contemporary knowledge about Mars and modern building technologies are sufficient enough to suggest many absorbing attention solutions to create a human-friendly architecture on the Red Planet.

Classification and the order of presentation of concepts seems to be complicated. It is so, because the systematics may base on variable methods of dividing, which are parallel. The author suggests here the order of concepts according to:

1. TYPE OF THE PROJECT
   (a) a net
   (b) an open space plan
   (c) intermediate solutions
2. LOCATION IN TERMS OF THE TERRAIN
   (a) on-surface bases
   (b) earth-sheltered bases
   (c) partially earth-sheltered bases
3. LOCATION IN TERMS OF THE HARSHNESS OF THE TERRAIN
   (a) a base in the lava tunnel
   (b) a base in the slope
   (c) a base in the crater
   (d) a base independent from the harshness of the terrain (e.g. an underground base or on the considerably flat terrain)
4. EXPLOITET TECHNOLOGIES
   (a) metal constructions
   (b) ground constructions
   (c) layed with stone constructions (e.g. made from brick, from stone blocks, or from concrete blocks)

   (d) pneumatic constructions
   (e) Shape Memory Polymers constructions
   (f) ice constructions
   (g) drilled constructions
5. TYPE OF COATING
   (a) ground coatings
   (b) rock-layer coatings
   (c) water coatings
   (d) pneumatic coatings made from panels
   (e) pneumatic coatings with a tightening net

There are shown nine models if Martian bases later in this chapter. A short description explains: what technologies are exploited in a given solution, how a form of the base is shaped, and functions of the interiors. The concepts are illustrated with visual explanation each one. Additionally, there are shown links to the above criteria with each of the presentation. It should make easier to work out searching the concepts in terms of different points. For example, if making bricks seems to become economical, there will be very easy to find all possible solutions exploiting this technology.

Concept 1

1a—a net

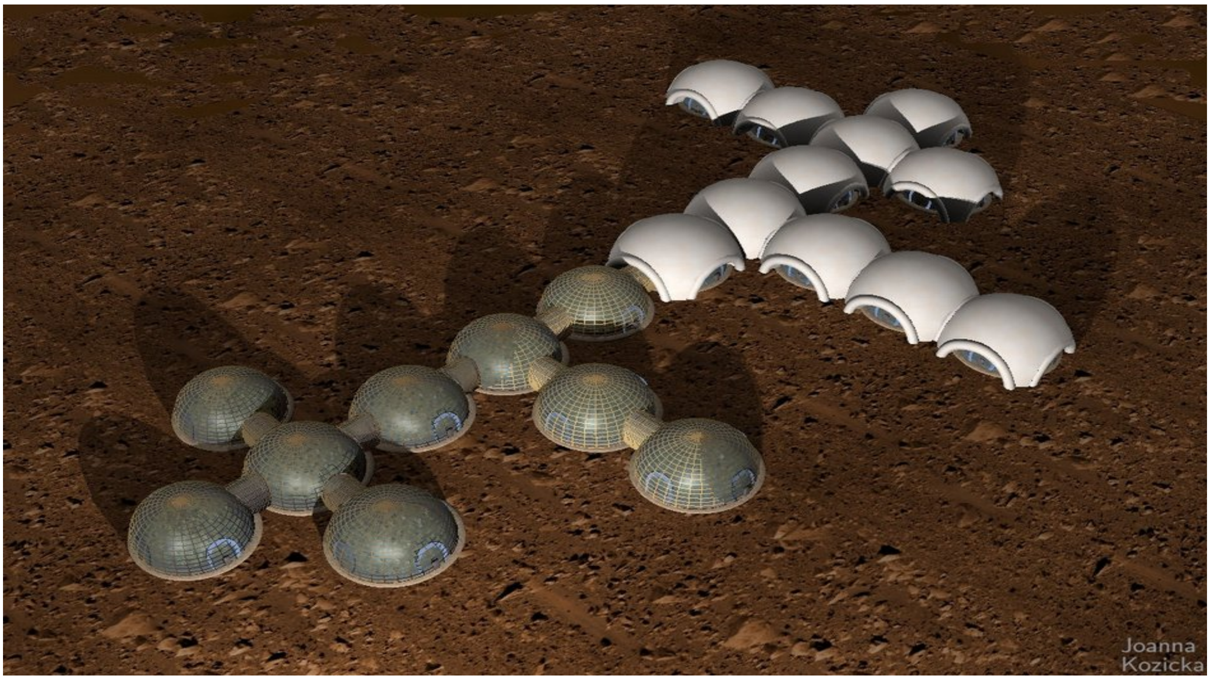
2a—on-surface base

3e—a base on the flat ground

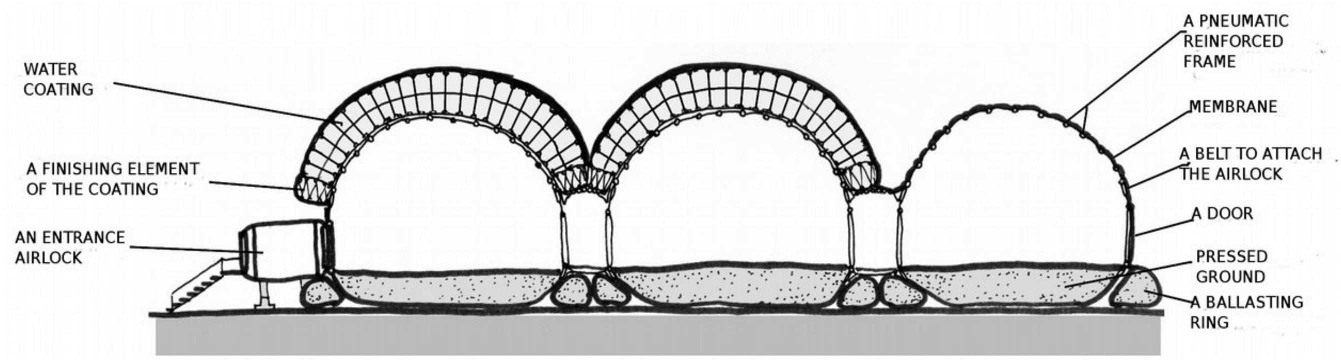
4d—pneumatic construction

5c,e—a water coating of the working-living part, pneumatic coating with a pneumatic tightening net over the agriculture area

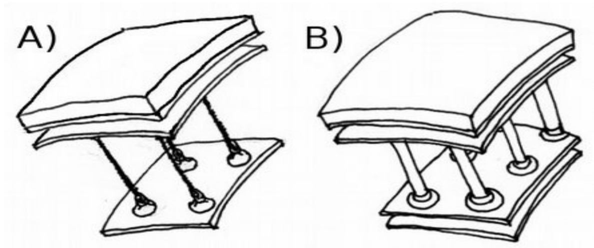
In the Concept 1 (Pict. 7.1, 7.2) there are suggested a module in a form of the pneumatic dome, reinforced with a pneumatic rigidized frame creating a net on the building surface. The frame keeps a shape of the module, even in case of atmosphere leaking, or a cumulation of the weight. It also rigidifies the membrane, which becomes less vulnerable to strong wind blows. A bottom part of the dome in layed with thermal isolation from flexible aerogel, and covered with pressed Martian ground, what allows for the ground floor to be made even in the residential area, and to grow plants in the agriculture area. A layer of the ground presses the pneumatic element to the ground, and balances its position on the ground. Additionally, every module is equipped with a peripheral belt made from a ground to ballast it. A bag filled with ground, put in a shape of the ring, reinforces a balancing system of the base, and reinforces flexible airlocks; the airlocks connect modules into a net. Every element of the building is equipped with doors on four sides, and a belt around the doors to attach an airlock. Planning doors on four sides of each module allows building a flexible base. Modules may be connected and disconnected easily to introduce changes in their configuration. A module may be attached to a metal construction with an entrance airlock. Chosen elements may be covered with a protective coating. In the Pict. 7.3 there are shown details of two variants to make such coating. Example A) relates to a ZORB globe (Pict. 7.4) in which two airtight membranes are connected with each other with many lines of the same length to keep an even distance between the membranes; there is pressurized air pumped in between the membranes. There is a narrow upper pneumatic layer designed for Martian base, filled with pressurized air, which is connected to the lower membrane by Kevlar lines. The space between the lines is filled with



Picture 7.1: Concept 1—perspective



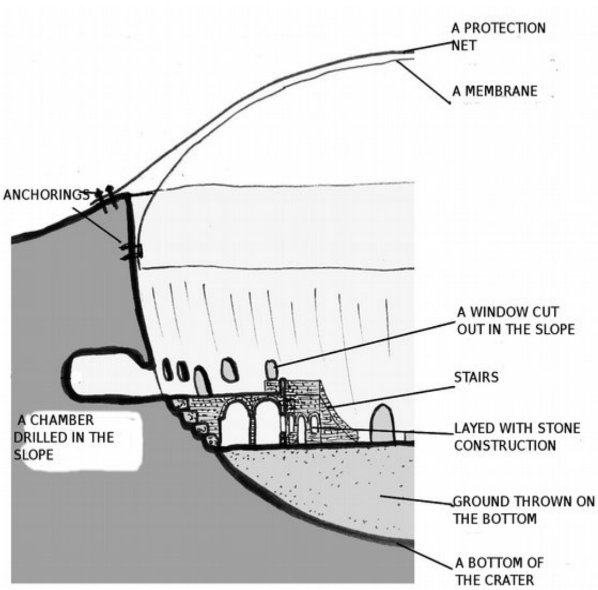
Picture 7.2: Concept 1—a cross-section with description



Picture 7.3: Concept 1—two variants of making a water layer (description in the text)

Picture 7.4: A ZORB globe (zorb.com)

water, which is the best protective material against the Space and Sun radiation, and at the same time a safe one to use and easily available. In the second variant it is suggested to make membrane tubes to connect the two pneumatic layers: the upper one and the lower one, creating a firm frame. This way the whole construction would be pumped in at the same time, and any leaks would be easy to complement. There should be two valves in the layer: one to fill it with pressurized gas, the second one to introduce water to the space created by the frame construction. The thickness of water layer and a number of water coatings would depend on the requirement for anti-radiation layers, and on the deadweight of the construction. The coating should be protected with thermal isolation on the outside to keep water in its liquid state. Additionally, the coating could be equipped with heating foil. The coating could be in a form of a section of the sphere to leave uncovered place around the doors on each of the sides of the module. The same way the sunlight could be introduced into the module, and it would give a good view on the landscape. Demron curtains would protect the residents, especially during the Sun storms.



Picture 7.5: Concept 2—a cross-section

A structure of the whole base is based on the exploitation of three main elements: a dome, a coating, a passage airlock. The domes may be connected in different configurations with flexible airlocks. A part of the complex of domes may be covered with a protective anti-radiation layer. The author's model is a net planned on the main communication duct. The base is divided into two zones: working-living—the main habitat, and for plants growing—agriculture part. The most important for the plants is natural illumination. It is the cheapest energy to achieve on Mars. That is why those modules are uncovered in this concept. There could be taken into consideration thin demron coatings to be thrown over those modules during the Sun storms. Working-living modules should have a very good anti-radiation layer at the expense of natural illumination. Water protective coatings are planned for this main part of the base.

The base requires a considerably flat terrain. However, there is no need to make it completely even, because the bottom parts of modules are filled with ground, and may adapt themselves to uneven surface, and the floor would be make even on the specified level. Light, flexible modules and coatings, packed, would be transported from Earth. Their installation, mostly pumping air into the structure, would take part *in situ*. Pressed ground and water would be collected from local resources.

Concept 2

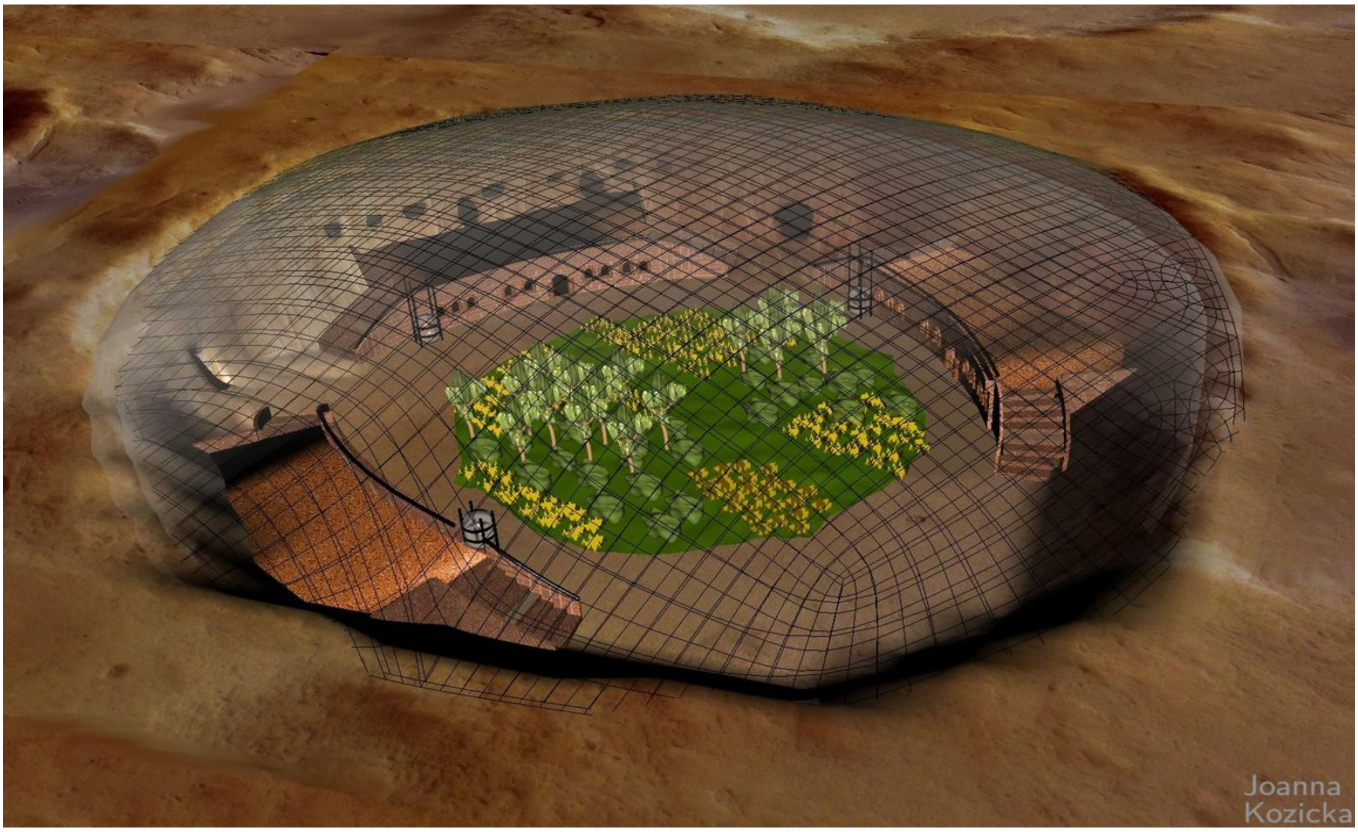
1b—open plan, strongly centralized

2b—a base in a terrain cavity, partially earth-sheltered completely

3c—a base in the crater

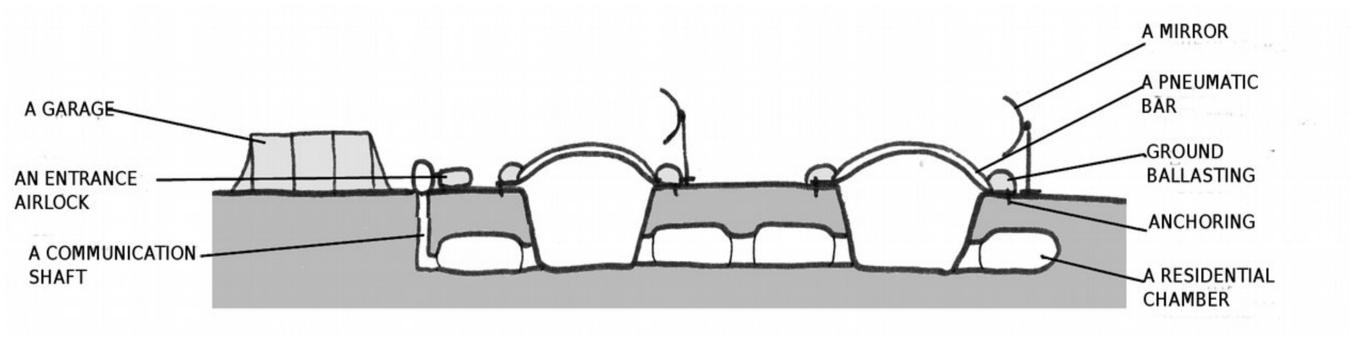
4c,g—layed with stone and drilled constructions

5b,e—pneumatic coating with a rigidifying net of the main part, drilled constructions covered with rocks

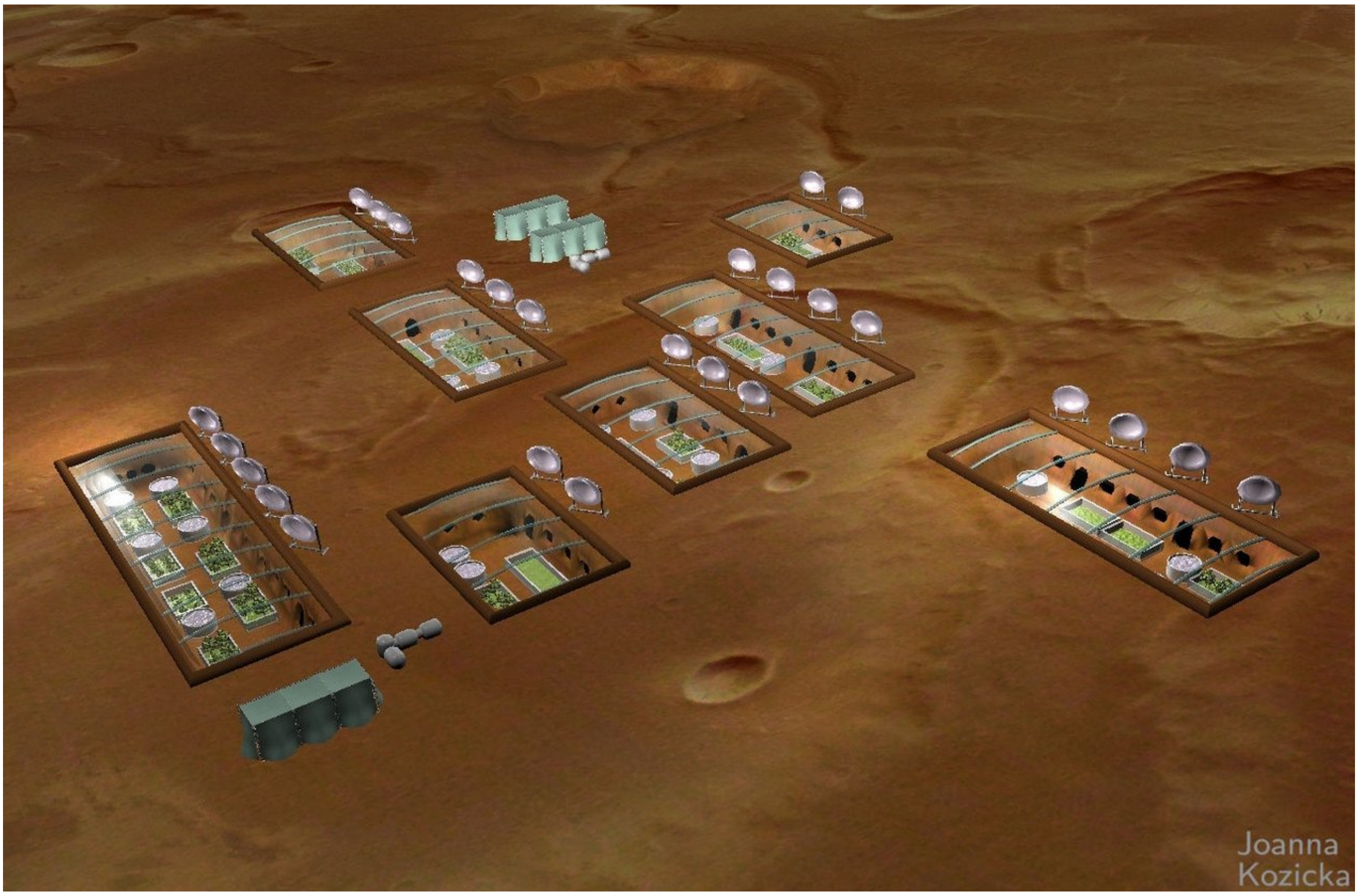


Picture 7.6: Concept 2—perspective

In the Concept 2 (Pict. 7.5, 7.6) a small Martian crater is chosen to build the base. Because its bottom is in the shape of a segment of a sphere, it should be covered with ground to create an even floor. This would also create a good ground for growing plants. The small crater is covered with airtight membrane, belayed with e.g. a firm Kevlar net anchored on the perimeter of the crater. In such obturated crater, filled with artificial atmosphere, it is possible to exploit different building technologies. Here, for the model, there are suggested drilled and layed with stone constructions. Chambers hidden in slopes of the crater would be protected better from the Space and Sun radiation. Layed with stone houses are similar in their construction to those on Earth, what would enhance the psychological comfort of the residents. There are planned two floors in the habitat, where a ceiling of the lower part would create a large terrace for the upper part. The underground working and residential part with windows is planned on the upper floor. There are artificially illuminated tunnels on the bottom level. There may be planned such functions as: storage facilities, technological, and to work. The communication between floors is provided with glamorous, layed with stone stairs, and comfortable, panoramic, small lifts, pneumatic constructions on metal rails. The smaller the crater is, the most difficult it is to fit in layed with stone buildings, and to find space for agriculture.



Picture 7.7: Concept 3—cross-section



Picture 7.8: Concept 3—perspective

However, it is easier to build a smaller airtight coating for a smaller crater. To make sure that such a base would grow larger, there should be many small craters in vicinity of the chosen localization.

Natural illumination is a great advantage of this base, as well as its large public place surrounding green gardens, creating a sense of community, safety and closeness to the nature.

Concept 3

1a—a net of underground tunnels around the cultivation fields freely set on the terrain

2b—an underground base

3e—a base in a flat terrain, where changes would be introduced

4g—drilled construction

5b,d—a roofing made from rocks above drilled constructions, and oblong skylights made from panels over open holes

The construction suggested for this model of the base (Pict. 7.7, 7.8) is built in several stages. First, a deep hole is excavated, on a rectangular plan. Its depth depends on the durability and radiation absorbency of the rock-mass around. The skylights are covered with demron curtains during the Sun storms, and they stay uncovered for the rest of the time. That way natural illumination would reach the insides and illuminate the plants grown at the bottom. For deeper holes there are suggested mirrors directing focused sunlight to intensify natural illumination. It would create larger independence from artificial, energy consuming, light sources.

The space for working and residential purposes is covered to protect it against the Space and Sun radiation with the rock-layer above. Natural illuminating would be let inside through the windows, and they would allow the view for the green agriculture. The exits to the surface would be provided with the shafts, where are lifts planned and, additionally, stairs. A vertical tunnel would reach a module on the surface, with a preparation for EVA room and entrance airlocks. There are garages for Martian vehicles planned near the module, which would not be filled with artificial atmosphere, and their construction do not need to be very durable. It is suggested they would be made from a light pneumatic reinforced frame, with suspended coatings to protect the vehicles from Martian dust.

The model of the base is planned considerably freely. Agriculture plans are of different length. There are also planned water tanks in there. Some of them may be prepared for breeding fish or for small recreational swimming-pools to enhance the comfort of base. A projection of rooms may be more regular and strict, or variable according to their functions, or according to the harshness of the terrain. There may be natural ditches available to be used, or obstacles that should be bypassed.

Concept 4

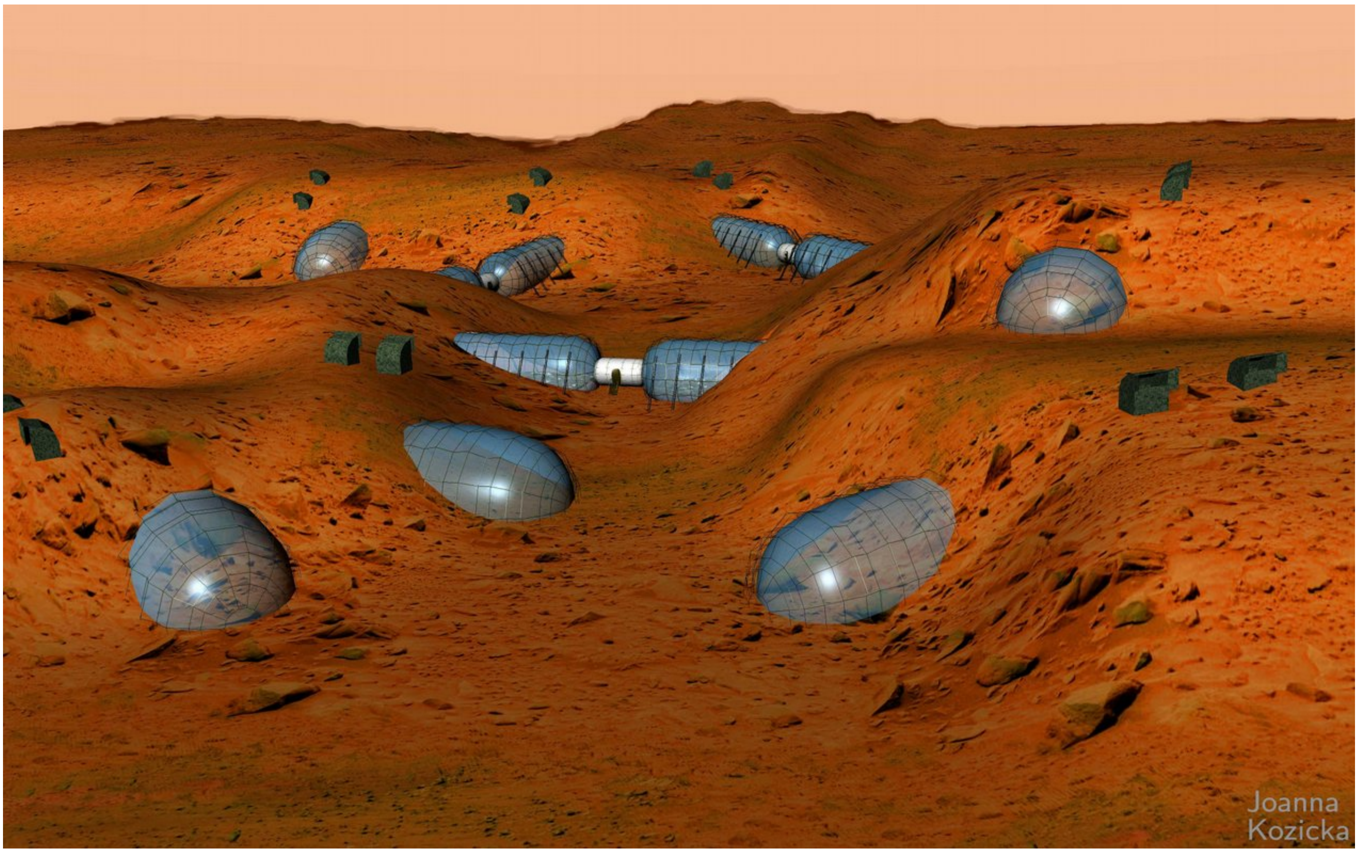
1a—an irregular net plan, written in the terrain

2c—a partially earth-sheltered base

3d—a *chaotic* base

4d,g—pneumatic and drilled constructions

5b,e—rock-mass covering over underground parts of the base, pneumatic constructions reinforced with a Kevlar net around them

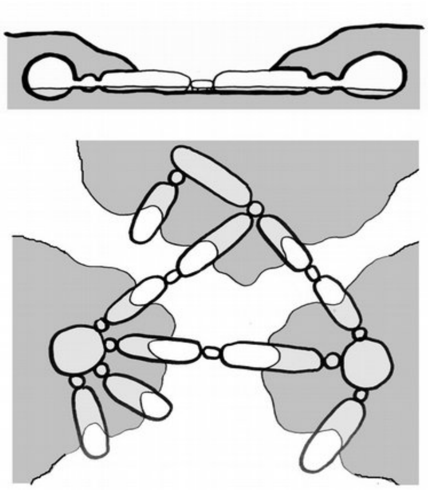


Picture 7.9: Concept 4--perspective 1

In the Concept 4 (Pict. 7.9, 7.10, 7.11) a base is designed as *chaotic*. The exploited terrain is full of hills, which are close to each other, and separated with narrow valleys. There are planned excavated tunnels in the slopes, into which there are partially inserted cylindrical, oblong pneumatic modules. That way a fragment of each module is build inside the anti-radiation rock-mass. It is suggested to plan in those parts residential zones, laboratories and technological rooms. At the same time, the other part of a module would be well illuminated with the sunlight, and would create a passage way for the sunlight to reach the underground parts of base.

Modules are connected in a net written into the harshness of the terrain, that is why their plan is so irregular. They are connected to each other with metal airlocks on the surface. There are planned spherical chambers underground, which function as communication junctions. They are also the best place to direct media from them. Thus, there should be planned the main PC LSS equipment. The underground parts of pneumatic modules and underground chambers are illuminated with natural light through periscope windows, which endings reach above the ground surface in a form of small turrets.

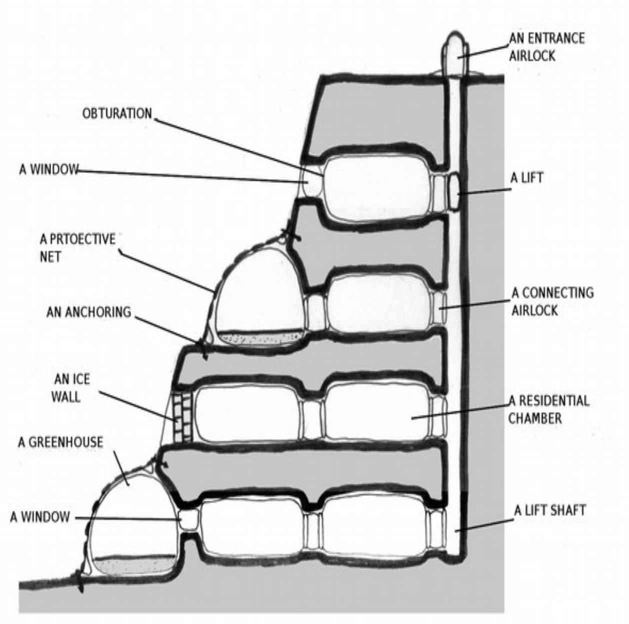
Picture 7.10: Concept 4—perspective 2



Picture 7.11: Concept 4—a cross-section, a horizontal projection

Pneumatic modules of a round cross-section should be partially filled with a layer of ground to achieve there a flat floor. It would create a ground for plant-growing in the agriculture zone.

A diverse, multi-functional space in every module of the base is achieved that way. It does not matter where an individual lives, because everyone would have a view at the surrounding landscape, and live close to the green area. Every module, thanks to that, is also partially self-sufficient. A failure of one module would not put the whole base into danger, the base would survive. However, there are also some disadvantages of that model: the plan of the base is complicated and communication from one place to another is problematic, and takes a lot of time. During a higher Sun activity, there is possible for the communication to be cut off to different parts of the base, if the surface connection places are not covered for the time, e.g. with demron coatings. Demron should be used in a form of curtains or roller-blinds. Every tunnel and chamber should be fitted with



Picture 7.12: Concept 5—a cross-section with description

Thermal insulation to avoid leaks of warm air into easily getting cold rocks on Mars.

Soft Cryogel would be attached to the walls, where it would additionally cover any uneven, sharp parts, and ensure a coating protecting against breaks in the obturating membrane.

The base should be localized in the vicinity of *chaos* to ensure efficient passage to an open space, and to explorated area. At the same, inserting it deeper into such *chaotic* terrain would create a good protection of the base against wind blows and dust accumulating on the base, and against extreme temperature changes. Deeper into the *chaos* hills are of more regular form, they are visibly less deformed by aeolian process.

Concept 5

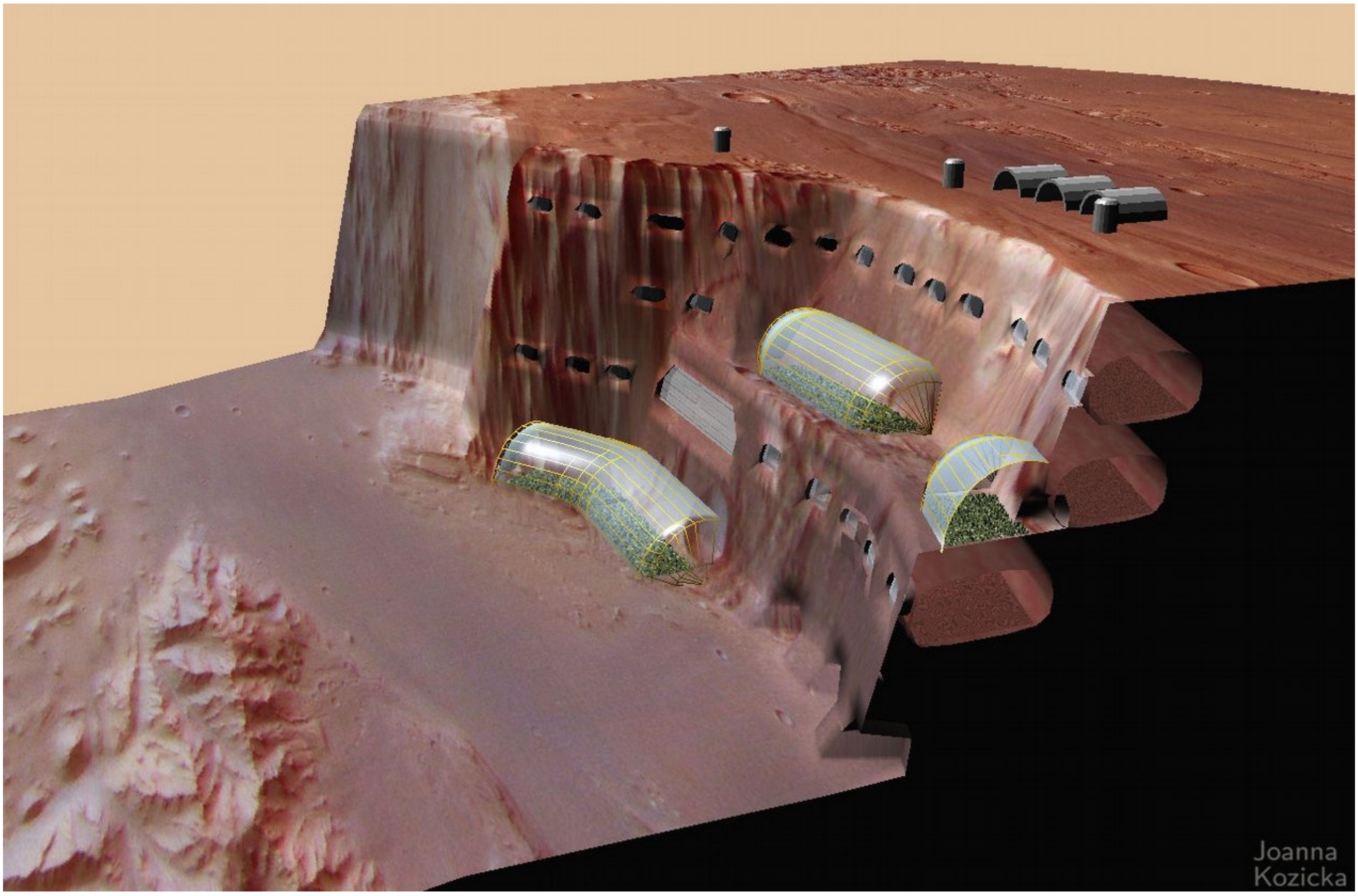
1a—a net plan, multi-level base

2b—an underground base

3b—a base in the slope

4d,g—drilled and pneumatic constructions

5b,e—rock covering over drilled constructions, reinforced with a net for pneumatic constructions



Picture 7.13: Concept 5—perspective

A model of the base in Concept 5 is designed in a slope—a bank (Pict. 7.12, 7.13). There is taken into consideration the use of rock shelves. The habitat is drilled in a rock, close to its surface, where there are cut out holes for windows. Because the slope is steep, there may be planned many levels, connected with communication shafts leading to the entrance airlocks. To make exploration easier of both the upper and the lower parts of the slope there are planned entrances in both those places. There are metal modules on the top of the hill, and at the foot of the hill, and there are cuts in the rock-mass adapted for attaching airlocks. They lead to the tunnels in the slope, where there could be Martian vehicles kept. They also could be used as temporary magazines. At the top of the hill, there should be built specific constructions to build garages. They could be vaulted hangars, tent-like constructed, providing protection against wind and dust.

The base is protected from radiation pollution by the surrounding rock-mass. At the same time, it is still illuminated with natural sunlight. Windows, cut out in the slope, invite the sunlight and give a view to the landscape around. Windows are obturated with air-bags, and larger openings—with ice-barriers. At the foot of the hill, and on the shelves (if there are any), there are suggested pneumatic greenhouses. Private cabins are drilled right behind greenhouses so they can have windows with a view of the gardens. Because the construction of this habitat is drilled on many levels, it is better to exploit mining technologies which do not require heavy equipment, as it would be difficult to move it between levels. One of PCF methodologies is suggested for the job. It is worth choosing such a site where the rocks are durable, but easy to process, and tuff would be the best choice here. To process basalts there would be explosives needed. To assure stability of the drilled rock-mass there should be kept a safe distance between the levels. That way they would be rather far away from each other. Long stairs connecting levels would dissuade habitants from going up and down often, so there should be at least several efficient lifts installed.

Concept 6

1c—large modules on the open plan, connected in a tight net

2a—a base on the surface

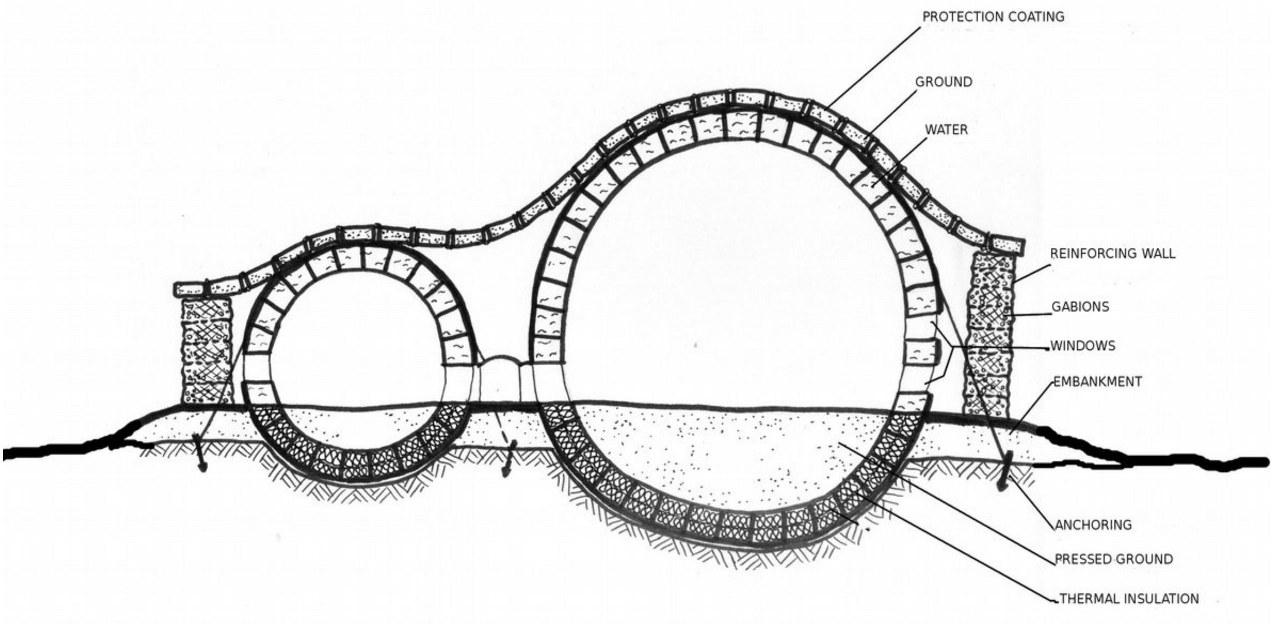
3e—a base on the flat terrain

4d—pneumatic construction

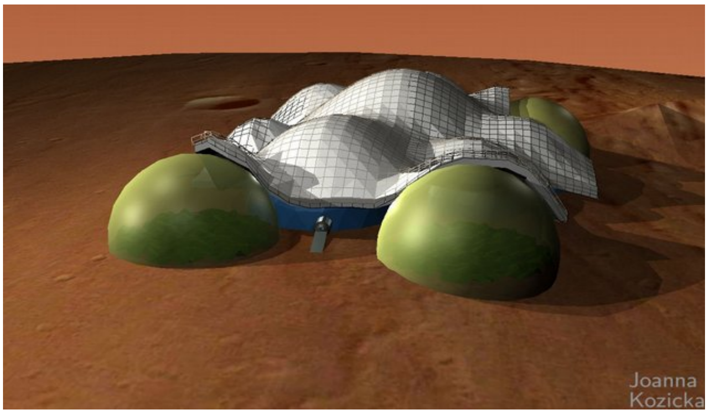
5a,c—water and ground coatings

In the Concept 6 (Pict. 7.14, 7.15, 7.17) the base consists of pneumatic spheres in different sizes. They are earth-sheltered in shallow excavations, anchored with resistant ropes, e.g. Kevlar or Vectran. Next, the spheres are filled with ground inside to the specified level of the floor. In the same way the embankment is made from ground around a sphere to build an exit from the base at an even level with the floor. To make the exit more comfortable, there would be build also a ramp or a way gently sloping down to the surface. To connect spherical modules there are suggested flexible airlocks.

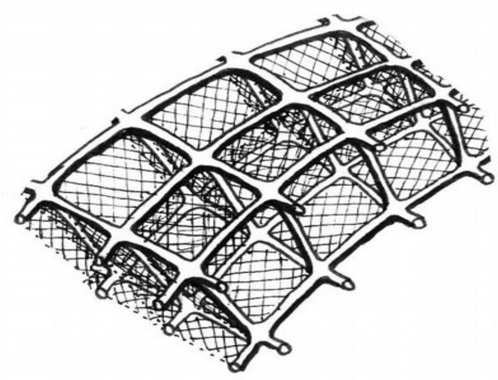
Every dome has got a spherical coating connected with the construction. An underground part of the coating is filled with thermal insulation and with the ground, if needed. Thermal insulation of the thick part would be made from Shape Memory Polymers, of porous, spongy, or foam structure. The above surface part would be filled with water, which would also protect the habitat from the Space and Sun radiation. At the same time, it would function as a water cistern. The Pict. 7.16 shows a detail explaining the suggested structure. It is a



Picture 7.14: Concept 6—a cross-section with description

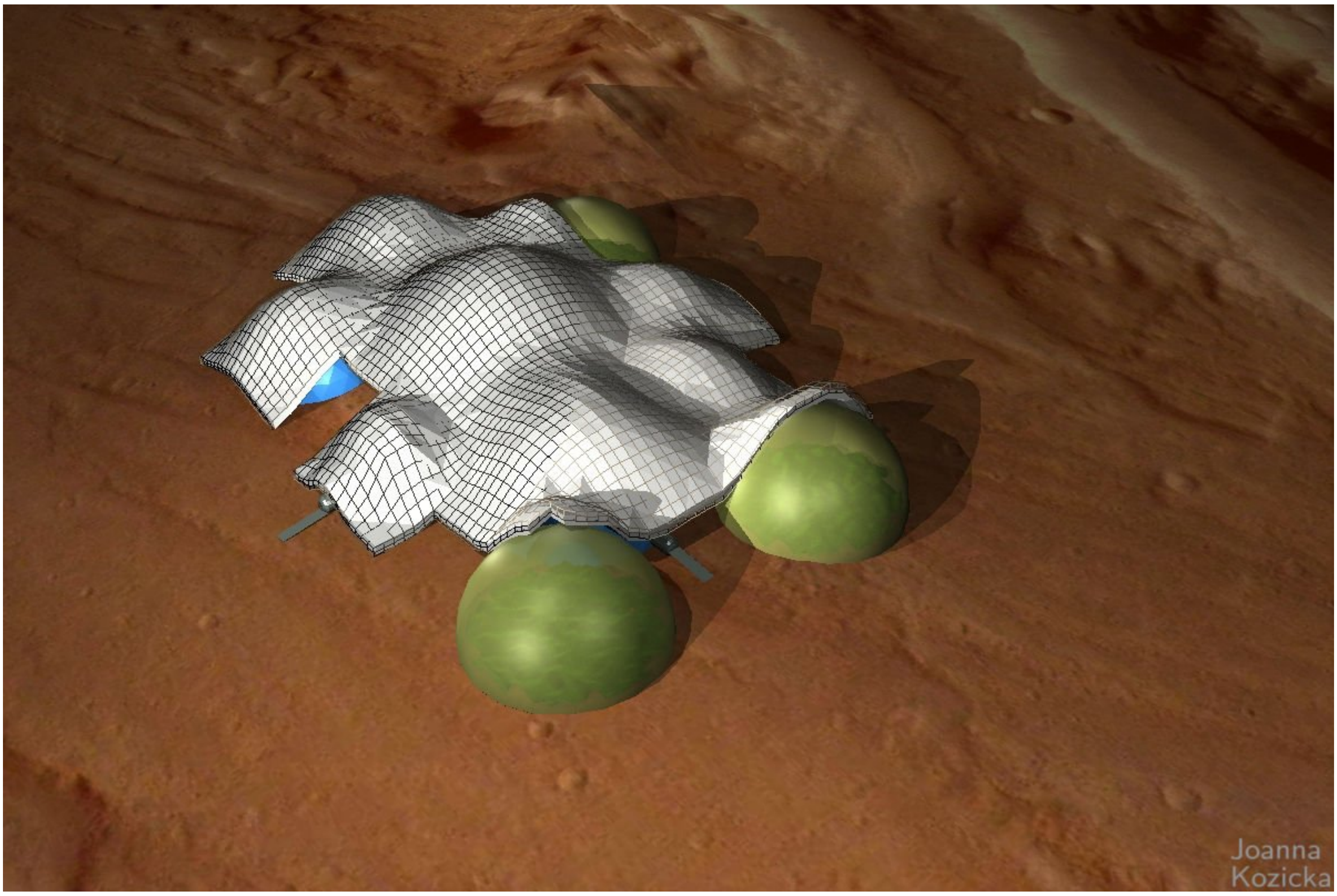


Picture 7.15: Concept 6—perspective 1



Picture 7.16: Concept 6—a detail of the water layer

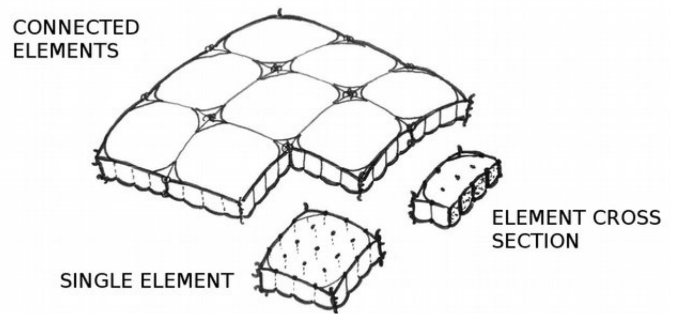
pneumatic frame with net-divisions. A cuboid water tank is inserted into each chamber, with thermal insulation, or a packed ice-block. The larger the dome, the more burdensome filling up such a water layer is. Apart from this, some of the chambers would stay empty to introduce natural sunlight to the insides of the dome. It would be a real advantage, especially for the domes housing agriculture. Empty chambers would also function as windows. There should be planned in advance places for doors, where the chamber-structure would be broken to create a larger entrance hole. A thickness of the water coating should be calculated to be adequate for the deadweight of the structure, and to create a good anti-radiation protection. Even if water is available on Mars, it might be really difficult to collect it in large quantities. Taking all of this into consideration, the thickness of water coating should not be planned too large. To protect the base better, the author suggests an additional cover in a form of the ground coating. A detail in the Pict. 7.18 shows its structure. There are cube bags filled with ground. Stable measurements are achieved with the inside reinforcing lines, connecting the bottom and the top of each bag in many points. Every modular element is equipped with clips at the edges (Pict. 7.19) to connect the bags together. This modularity ensures building coverings of spheres in different configurations, and creating openings for skylights. A detail in the Pict.



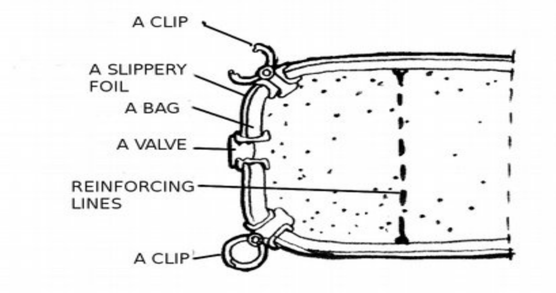
Picture 7.17: Concept 6—perspective 2

7.19 shows a detailed cross-section of such a bag filled with ground. A smooth, slippery surface of the foil, e.g. EFTE, inside the elements ensures that dirt and Martian dust would not stick to its surface. There could be also attached additional demron coating for this element, to ensure better radiation absorbency of the coating. This coating could be broken at any point, e.g. over the ground level, or on the agriculture module. The bags at the edges would be attached to the ropes anchoring the dome, with clips. It is suggested that the coating would be built over the entrances leading to the airlocks in metal modules. The coating would be supported there with gabion pillars, or with rock blocks. It would also create a roofing over the windows to lessen radiation pollution reaching such openings.

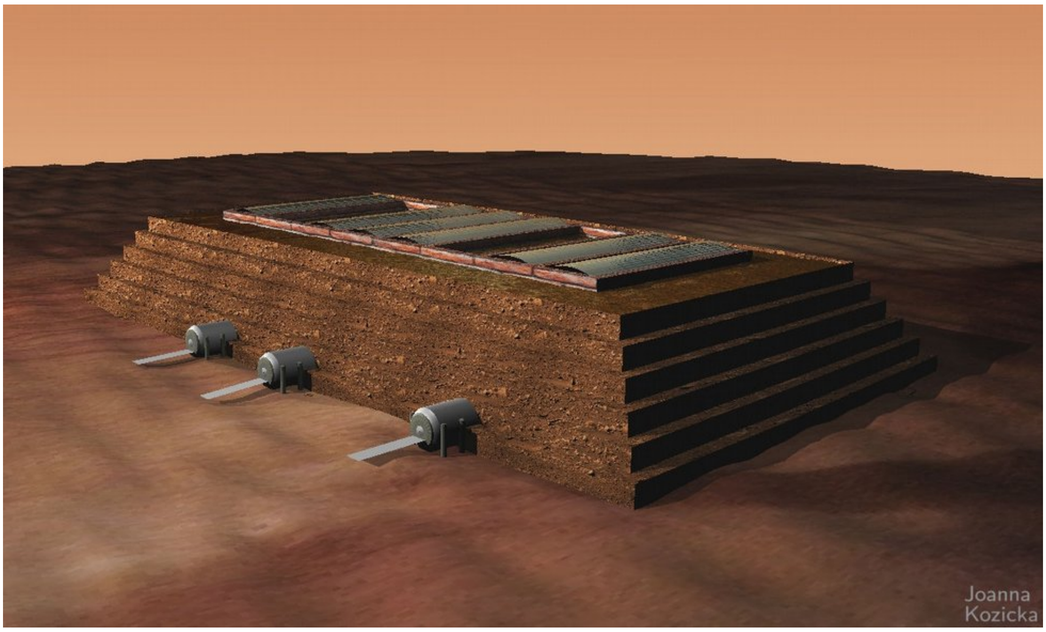
This model of a base is exceptional because of a very good the Sun and Space anti-radiation protection. Domes in different sizes allow for a good orientation in every place of the base. At the same time, the base looks more attractive on the outside. There are spheres in three sizes in the model. Earth work is limited to excavation of the amount of ground which should be enough to fill bottom parts of the spheres, and building an embankment around the spheres, and to fill the bags of the protective coating.



Picture 7.18: Concept 6—details of protective coating



Picture 7.19: Concept 6—a cross-section of AN element of the coating, with description



Picture 7.20: Concept 7—perspective

Concept 7

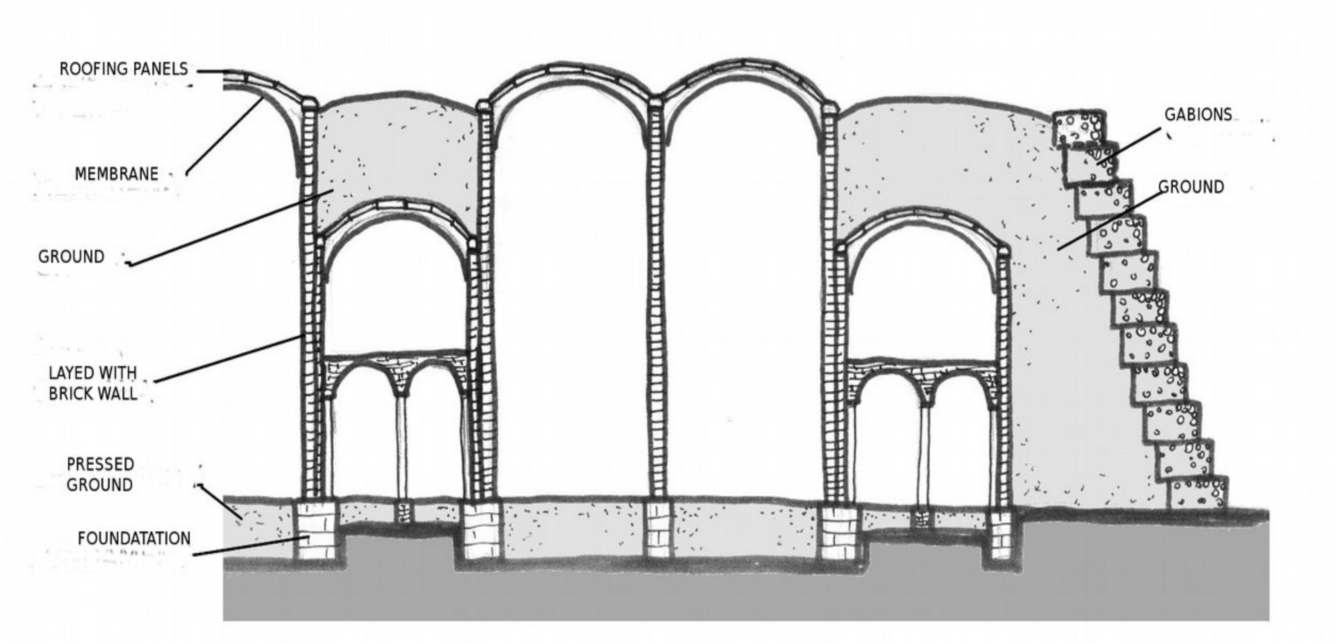
1c—a habitat creates a net around large agricultural areas

2a—a base on the surface

3e—a base on the flat terrain

4c—layed with stone construction

5a,d—agriculture areas are covered with a pneumatic coating, with roofing panels, the rest of the base is covered with ground



Picture 7.21: Concept 7—a cross-section with description

In the Concept 7 (Pict. 7.20, 7.21) a construction of the habitat is layed with stone. There could be used cut rocks, stone or brick blocks. There are straight walls layed mainly, and only in the halls, there are arched vaultings (or domes) built, of considerably small span. The anticipated roofings are pneumatic obturating membranes, with panels on the edges attached to the gables of layed walls, to protect the membrane against mechanical damages. The membrane is clear transparent, and panels are made from transparent polycarbonate. The roofings over the growing fields are attached high above them, and those over the residential area—low enough to achieve even ground to the height of the top skylights. Ground should create a protection barrier against the Space and Sun radiation. Natural illumination for the cultivation would be achieved with the top skylights, and for the residential area—with the windows offering a view of the gardens. The outside walls would be tighten with the outside regolith layer, in a form of an embankment. Its slopes would be stabilized with gabions.

In the concept model there are suggested three separate cultivation areas of different sizes. There are oblong, two storeys halls around them, housing residential-working chambers. There are openings in different sizes for windows in the walls that would allow for observation of green parts from residential area, and to let the light in. This base is built on a flat surface. Apart from the roofings, metal airlocks and woven wired mesh baskets, the whole construction is built from materials obtained from local resources.

Concept 8

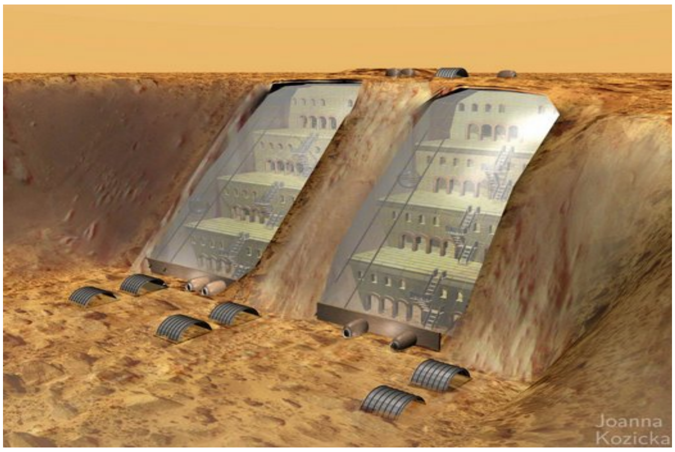
1c—multi-storey, open, terraced habitat

2c—a base partially earth-sheltered, inserted into a slope

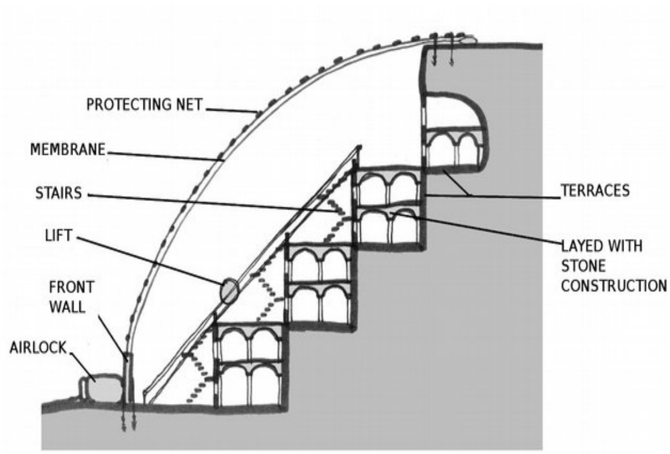
3b—a base in the slope

4c,g—layed with stone, on terraced excavated slopes constructions

5e—pneumatic roofings, rigidized with a tightening net



Picture 7.22: Concept 8—perspective 1



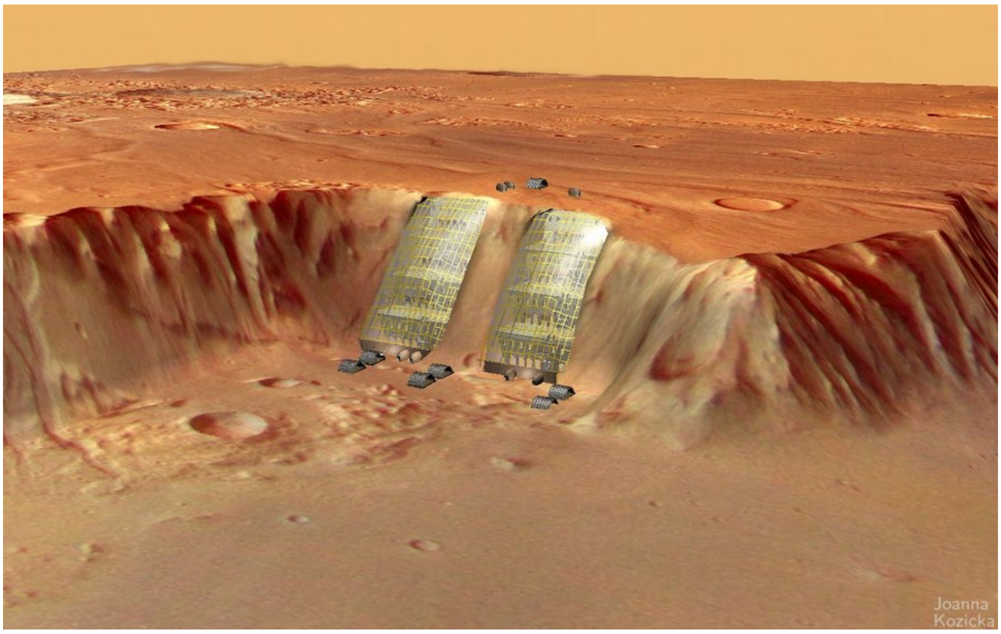
Picture 7.23: Concept 8—a cross-section with description

In the concept 8 (Pict. 7.22, 7.23, 7.24) a base is built in the slope. There are excavated terraces on a chosen building site, on the slope. The excavation is covered with an air-tight transparent coating. It is anchored on its perimeter, and at a foot of the hill it is connected with a metal wall; there are also metal airlocks connected to the same metal wall. The stability of measures of the membrane, tighten with the inside pressure, is achieved with Kevlar lines anchored to the slope. Such connection of the membrane to the net allows keeping it up even during larger gas leaks. This airtight membrane is really large. However, due to its rectangular shape it is considerably easy to make—in comparison to a torus or a dome. It is also easier to put in place. The Kevlar net tightens it well and reinforces it, protecting the membrane against the large pressure differences.

There are garages close to the metal wall, built as separate vaultings, on unfolding frames, or with pneumatic ribs. Their covering is light—a coating. There could be also an exit from the base at the top of the hill. It would make some larger terrain to be easier available for exploration, and in different directions. However, it requires the base to be connected with underground tunnels, leading to the airlocks at the top. It is highly probable that the same equipment would prove itself useful to make the tunnel, which should be used to build terraces.

There are traditional layed with stone constructions on the terraces. Their height and width depend on the angle of the slope. It would influence the optimal number of storeys, and the width of the construction. There are designed one storey constructions built on four levels in this concept (Pict. 7.23). The communication is provided with lifts and and stairs. Stairs are made with unfolded construction, made from light metal alloys, or a durable plastic. Lifts go on the slanted rails propped on the edges of terraces. An elevator may be built in a form of a ZORB globe, or a cuboid expandable construction, with a floor panels inserted, and a reinforcing net on its sides and the ceiling.

The roofings of layed with brick-stone constructions would create a manageable terraces, public places, or places to build greenhouses. Water tanks layed on the surface of such a terrace would make a good protecting barriers against the Space and Sun radiation. Without such protection, or its insufficient radiation absorbency, there should be an additional shelter planned, best deep in the slope, or in a separate building, prepared sufficiently to protect people against the Sun storms. As the whole base is coated with the membrane, a traditional brick and mortar method of building would not be a problem. Layed with brick constructions, as the best known from Earth, would calm down home-sickness, and create a well known warm every-day reality feeling. However, excavation residential chambers in the slopes would assure a better anti-radiation protection, and every terrace could be coated with a separate cover. In this case, during a gas leak only one part of the base should be evacuated, and not the whole. However, the isolation of the zones in the habitat would be more noticeable. One large area ensures better social contacts.



Picture 7.24: Concept 8—perspective 2

Concept 9

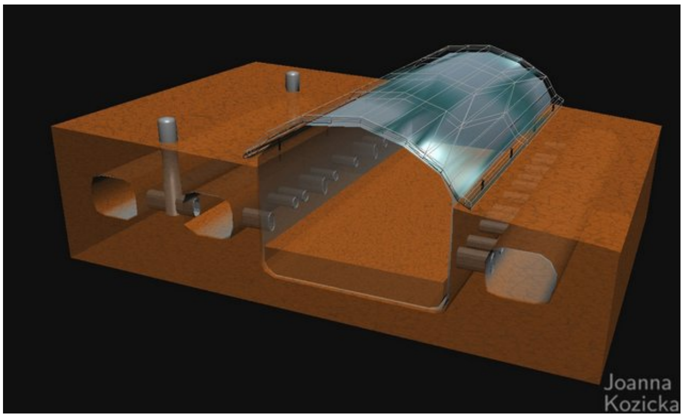
1a—a complex net plan

2b—an underground base

3b,c,e—a base located partially in the slope, partially in small craters, partially on a flat terrain

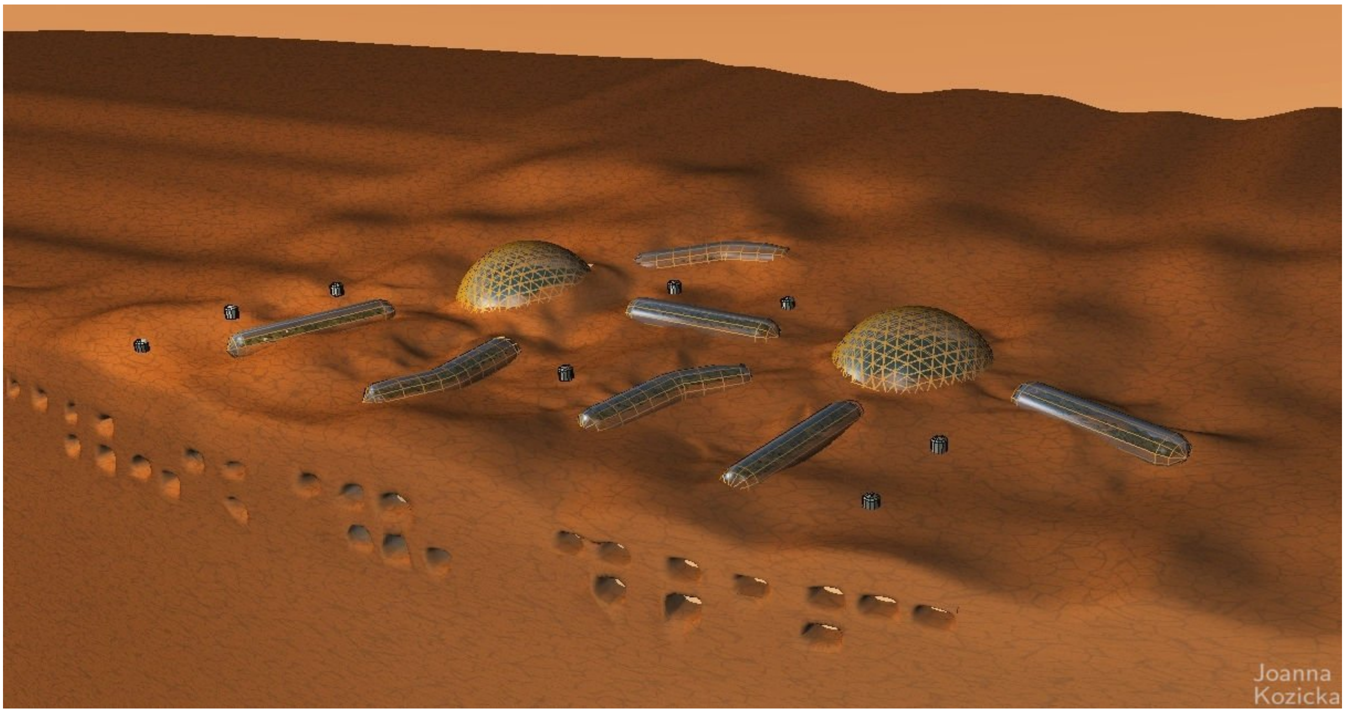
4d,g—drilled and expandable constructions

5b,d—rock roofings for drilled constructions, pneumatic roofings attached to unfolding constructions, with panels on them

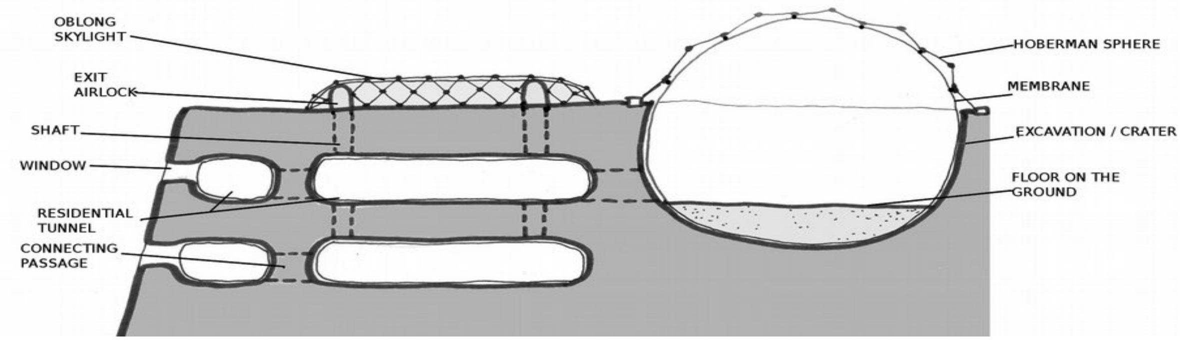


Picture 7.27: Concept 9—insides of the underground construction

The base in Concept 9 is of a complex structure (Pict. 7.25, 7.26). There are anticipated different building technologies to build it, to make the best possible use of the available piece of terrain, and to create a base with areas different in character. There is a large, open well illuminated with the Sun, and self-unfolding Hoberman sphere located in a small crater or in an excavated hole. It is covered with with self-unfolding Hoberman dome, with airtight coating suspended under the dome. There may be layed transparent panels to protect the membrane against mechanical damages, if necessary. The bottom of the crater may be covered with level ground. Due to the very good illumination and a large height of the dome, it is suggested to create cultivation fields in there, preferably high trees—e.g. banana palm trees, which adapted themselves especially well in Biosphere 2, giving large harvest of generally appreciated, caloric and healthy fruit. Apart from this, it is also a good place to plan a sports field, or for any other recreational facilities. Oblong hollows in the ground, natural or made for the purpose, may hold green fields. On the sides of those hollows there are suggested oblong residential tunnels to be drilled, with windows cut out in the slopes. The windows would offer the view of the gardens, and gain sunlight for the underground chambers. There would be a membrane attached above the hollows, an an oblong unfolding construction supporting polycarbonate panels (Pict. 7.27). Underground passages would connect tunnels into a complex net-system. Horizontal shafts would lead up to the airlocks at the top, and down—to lower levels, which would serve as magazines, maintenance rooms, workshops, manufactures etc., because they would be without any natural illumination. Some of the tunnels would be built along the slopes of the canyon, to cut out windows in there. As the residential chambers would be earth-sheltered but rather not very deep in the ground, they should be insulated. Making perforations in the slope, functioning as an outside wall of the habitat, imposes obturation of all of the tunnels, or at least the window openings. Windows could be obturated with pneumatic bags by pressing their surfaces to uneven rock around those openings, and anchored with tightening and connecting nets. With a use of clear membrane there could be assured a good view to the outside surroundings. However, to protect better the insides against the Sun and Space radiation, the openings could be filled with ice blocks; but they would let the sunlight in partially only, and at the same time—distort the view.



Picture 7.25: Concept 9—perspective

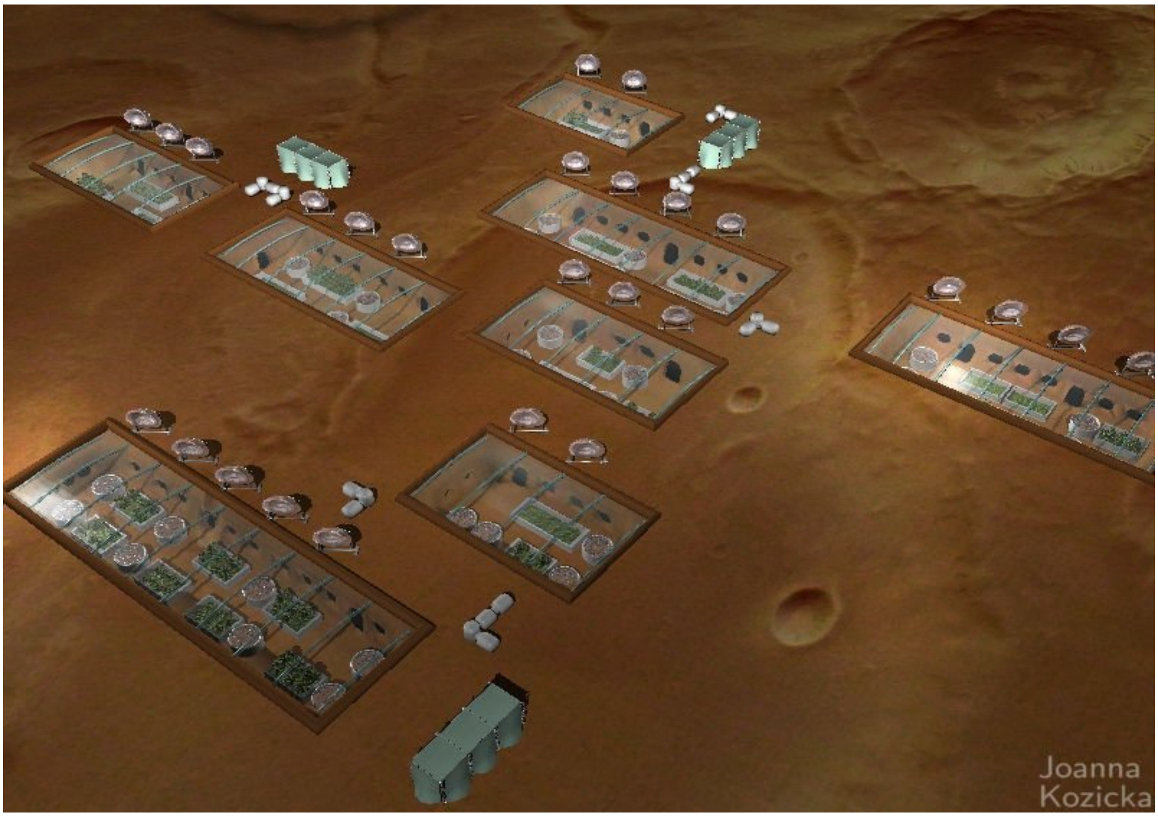


Picture 7.26: Concept 9—a cross-section with description

This type of base is mainly excavated, drilled, which require the same mining machinery, however, in several different forms. There are two types of roofings: domes and cylinders. Their installation is very efficient and simple, as there are self-unfolding articulated constructions used. The variability of impressions in differently shaped interiors would enhance an overall reception of the base, and break the monotony of restricted environment in extreme conditions. The habitants of this base would be able to choose a private cabin with a view of a green garden, or of the landscape of Martian canyon. They would spend much of their free time in considerably large open places under the dome, without any claustrophobic feelings. This model presents a rather large base, but there might be planned a habitat with one dome, and e.g. two courses of tunnels with clear roofs, and a short section of tunnels along the slope on one level only.

8 Design Concept of Martian Base as Habitat in Extreme Conditions

There has been chosen Concept 3 from among all of the models presented in Chapter 7 to make a more detailed presentation here. The architectonic project here shows a base as a set of groups of cultivation fields connected into a net system. There are underground residential-working constructions under each greenhouse. There are planned vertical shafts leading up to the greenhouses; at the top of the shafts there are small modules, housing preparation rooms and airlocks to exit the base. There are planned garages in the vicinity of the airlocks (Pict. 8.1).



Picture 8.1: Perspective of the whole architectonic design of the planned Martian base

The Concept 3 has been chosen for different reasons. The suggested base is independent from a form of the the terrain. Its default site is a flat piece of land, however, any natural hollows may be also exploited for the purpose (the base would be more irregular in its form then). Drilled and excavated constructions are also suggested in other models, thus the Concept 3 has been chosen as a representative one. The land formation and geological conditions in the building site may influence the setting of greenhouses (orangeries), and the method of underground tunnels junctions. It all results in creating an irregular, more picturesque architectonic view of the whole habitat (of course, a regular, ordered net system is also possible In more favorable terrain conditions).

It seems that technological solutions suggested for this concept are considerably economical. The author thinks so, because a rock-mass *in situ* is exploited here as the base construction, instead of transporting large amount of building materials and ready-made modules from Earth. Next, there has been chosen the technology of reusable objects, which allows expanding of the base, without the need of help from Earth. Once transported vehicles and equipment may be used many times (Kozicka 2007).

The base create a consistent complex of equitable architectonic units in a form of hollows, cavities with agriculture, and the underground ring of residential-working tunnels. Such a unit may be self-sufficient and create an independent habitat, providing that there are all of the required functions anticipated. A complex of such units allows people for better communication, function divisions, and more variability in the base, and a failure in one of the units does not compromise the existence of the whole habitat.

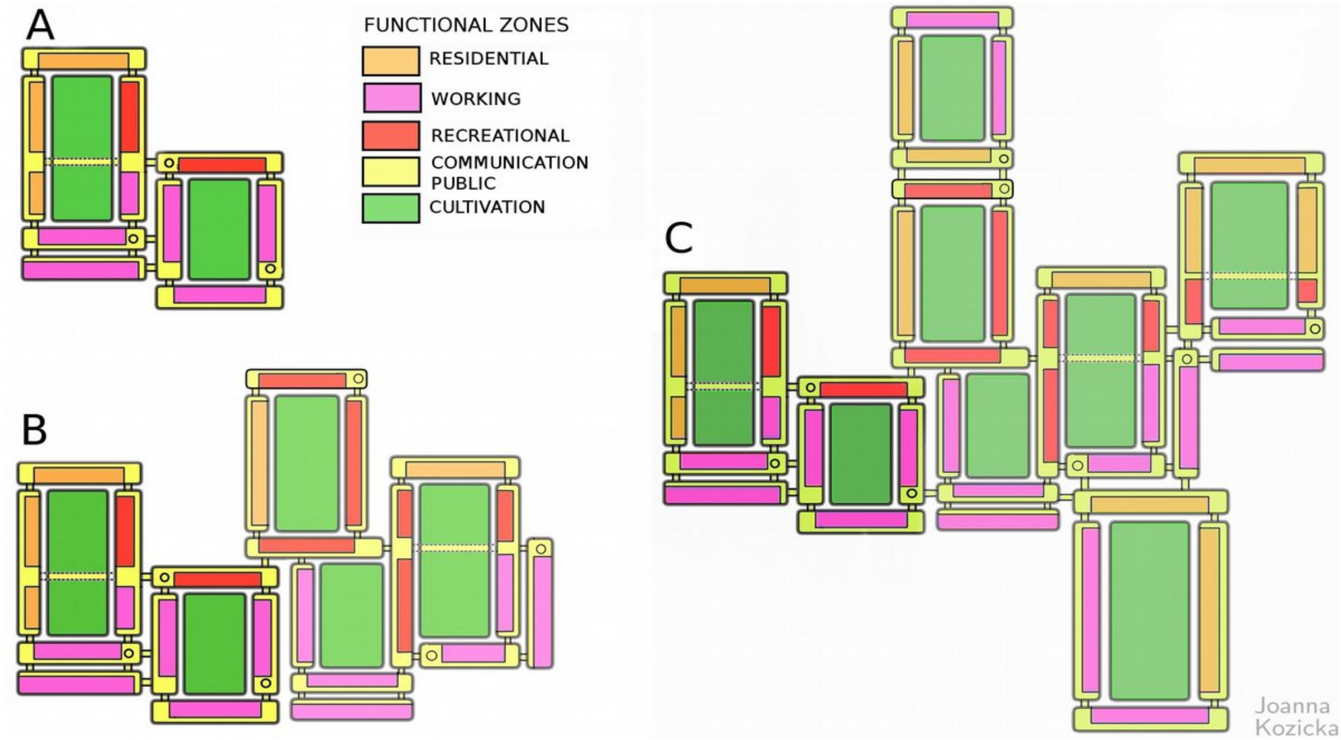
The earth-sheltered habitat ensures a very good anti-radiation barrier, protection against outside weather conditions, and mechanical damages of the construction. At the same time there is a good natural illumination because of the greenhouses coated with transparent roofs and the system of mirrors increasing the illuminance of sunlight reaching insides of the habitat.

This concept has many advantages. However, it should be emphasized that building this will be possible only when larger knowledge of geology of Mars is gathered (e.g. because of the researches of the ground at deeper levels as part of unmanned missions planned by NASA and ESA), and simulation of mining works in Martian rock-mass is conducted.

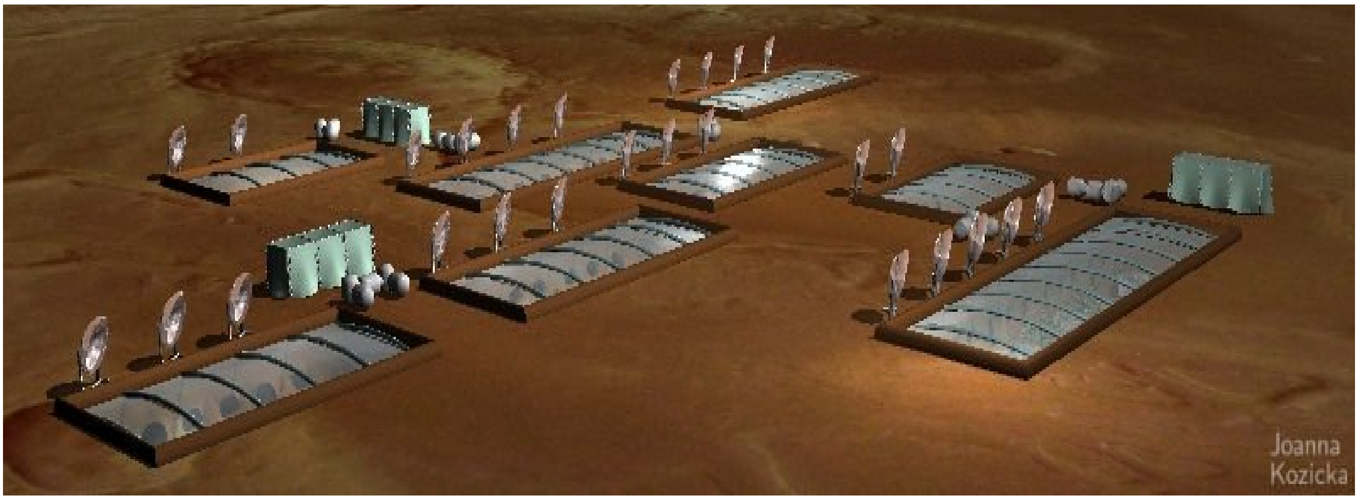
Function

In the Concept 3, as an exemplary model of Martian base, there are shown considerably large architectonic assumptions. It is an advanced habitat on a large space where several dozen of people may live and work. In the Pict. 8.2 there are shown projections of the underground base in different stages of expanding. At the first stage there are suggested two orangeries and surrounding it underground tunnels. At the second stage there are suggested excavations of three more of similar architectonic elements, and at the third stage—three more. The functions are marked with colors. It is an exemplary suggestion, which shows the means of functions division, which would not create conflicting points during an expansion of the habitat. The main communication ducts leading to the residential-working tunnels go through recreation zones. There are never in one tunnel placed residential and working chambers together. There are windows in places assigned for the constant exploitation by habitants, because such places are anticipated around greenhouses. Only tunnels assigned for magazines, maintenance and subsidiary rooms close to working places are without natural illumination.

The projections show a schematic plan of functions. Only with detailed calculations there might be decided the exact proportions of every function quota in the habitat. The calculations should take into consideration, among others: the number and the type of work places (laboratories, manufactures), and the area for BIO LSS in greenhouses to produce oxygen, drinking water and food for the habitants. In the author's concept project orangeries are in different sizes, what should improve the orientation in the habitat, and introduce variability into the artificial environment of life.



Picture 8.2: Horizontal projections with marked in colors of functions scheme, showing the stages of expanding of the base: A—first stage, B—second stage, C—third stage



Picture 8.3: The form of the base on the surface

Form

This base is an underground structure. An orangery (greenhouse) is a regular cavity on a rectangular plan. There are tunnels around it, creating oblong vaultings with openings for doors and windows. There are visible arched roofings over the orangeries (Pict. 8.3), airlocks and hangars with garages only.

Construction

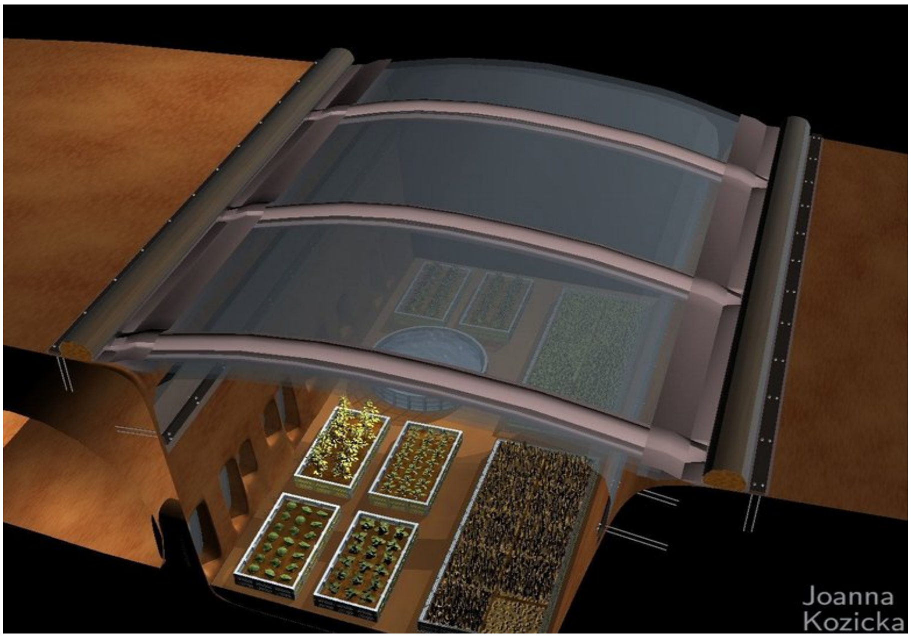
The base is set in the considerably flat terrain. It does not require removing stones and leveling the ground because the construction is earth-sheltered. The only required here smoothing of the terrain is anticipated for Martian vehicles for the needs of the base.

The main building technology used to built the base is drilling. It is assumed that there are durable, hard rocks of volcanic origins, such as basalt, andesite, tuff. The surface of Mars is shaped mainly by volcanoes processing, so a chance to find such a place is highly probable. Basalt and andesite are difficult to process, so to drill and excavate them, explosives would be preferable as the best for the job. Tuff may be processed with less invasive for rock environment methods. However, tuff appearance on Mars, although indirectly proved, applies only to some small parts of the Red Planet. As they are very hard rocks, it is assumed that a precisely built tunnel would have a self-binding vaulting, not requiring any additional casing. For the purpose there is chosen a curved cross-section of the vaulting, and not rectangular—which strictly requires supporting columns.

The thinner the dust layer is on the surface, the more shallow should be earth-sheltering of the base. It may create different additional advantages: less work with excavations, less output to transport from the excavation site, the bottom of orangeries would be better illuminated, the way to the surface would be shorter and requiring less effort.

There are excavations of two types made for the base: rectangular excavations covering a considerably large area, and underground vaultings for the tunnels. The contour explosion seems to be the best to make excavations—the artificial cavities in the ground. It would ensure the efficiency of excavations, ensuring smooth walls, and the smallest possible labor input. Next, there will be, close to the excavations, narrow shafts made, leading to the entrances to the underground tunnels. The cross-section of the planned tunnels are vaulted, about 5.5 m x 8 m, and different in length, adapted to the projection of excavation. Tunnels are hidden behind the slopes of excavated hollows, to protect them against cracking. And again, they should be made as close as possible to the open space, from where they will be illuminated with the sunlight through window openings. Those are reasons why the tunnels should be made with the use of less invasive for the geological environment mining technologies, and at the same time—equally effective. There is suggested for the purpose PCF technology, e.g. cardox. There are required for this method reusable cartridge-tubes (transported from Earth), and carbon-dioxide—there is abundance of it on Mars. It would be collected from the atmosphere, pressurized or put into the cartridge-tubes in a form of snow (if there would be carbon-dioxide in this form somewhere close to the building site). At last, there will be drilled openings for windows and doors in the span according to the plan.

The excavations would end at this stage. Next, the excavated hollows in the rock-mass should be obturated. Depending on the local rock hardness, the obturation of the excavation would be required exclusively, or for all of the tunnels around. There is anticipated an airtight roof only due to economical reasons, made in a form of a transparent coating. The excavated and obturated hollow may be filled with artificial atmosphere, and the management of the insides may start.

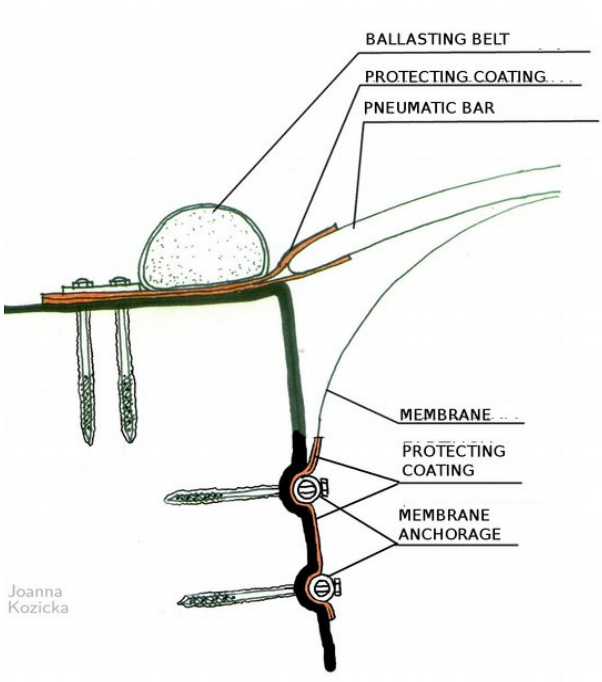


Picture 8.4: A piece of the coating—close view

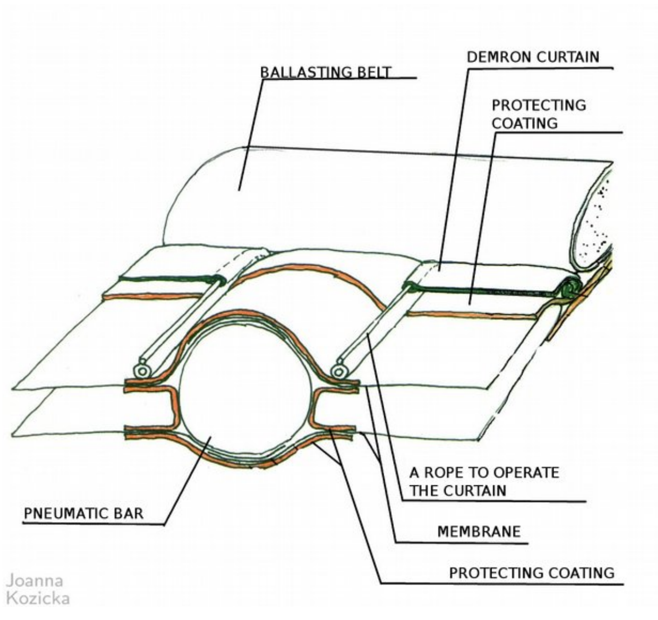
The Picture 8.4 shows the close view of a piece of the orangery coating. In the Pictures 8.5 and 8.6 there are shown details of agriculture coatings. It is a pneumatic coating, made from two layers. The first one is a separate obturating membrane, which should keep the gas and humidity of the atmosphere inside. It may be made from e.g. PCTFE foil. Its additional quality is a very high durability for perforations. Additional reinforcement with glass fiber would give it more protection against stretching, tearing and pulverizing, however, illumination permeability would be lower. Additional detailed calculations, taking into consideration the atmosphere pressure inside the base, would answer the question about a thicker PCTFE membrane, if several layers of it is enough (or another kind of foil of higher durability for stretching, like PI), or if a composite is required.

The upper coating, the second layer, is made from a pneumatic beams and panels installed between them. The beams are set on a regular span. They are filled with a mixture of gas to make them firm. Empty spaces are filled with atmosphere, pressure value in the middle between Martian atmosphere, and the artificial atmosphere inside the base. That way the foil of the bottom coating would be strained less. Beams and panels are firmly undetachable. The coating is made in one piece, its length adjusted to the size of the specific orangery. Because of its integrated structure it is easier to install it in its place, and there is a smaller chance of its dehermetization in joint places. The panels, foil and beams are welded together, the bottom layer separately, and the upper one in the same way, as it is shown in details in the Pict. 8.6. Welded spots are protected with coatings made from more durable, but not transparent material. The panels should be made from a material, which should comply with many standards at the same time: required level of transparency; perforation and stretching resistance; anti-static and resistance to dirt. It is so, as it has to resist strains caused by the artificial atmosphere, and interact at the lowest possible level with Martian dust. Additionally, this material should be resistant to UV radiation. ETFE seems to suit all those requirements.

Both of the coatings should be anchored into the ground. The obturating membrane should be reinforced in the specific fragment with a protecting covering on the whole perimeter of the orangery. There should be attached, to this reinforcing belt, a flat bar with two holes at a regular span, ready to put into them anchoring screws. The screws should be inserted deep into the wall of the slope, into prepared in advance drilled holes. The anchoring screws are empty-inside rods, with a row of small holes—to insert resin into the structure. Resin fills the empty space between a drilled hole and the rod.



Picture 8.5: A detail of the orangery coating anchorage



Picture 8.6: A detail of shaping the upper coating of orangeries

The resin is here responsible for the uniting the screws with the rock and reinforcement of the anchorage. The upper coating is similarly anchored, but on the flat surface of the land around the excavation. Additionally, it is ballasted with a belt made from long bags filled with regolith. The detail of ballasting is shown in the Pict. 8.5.

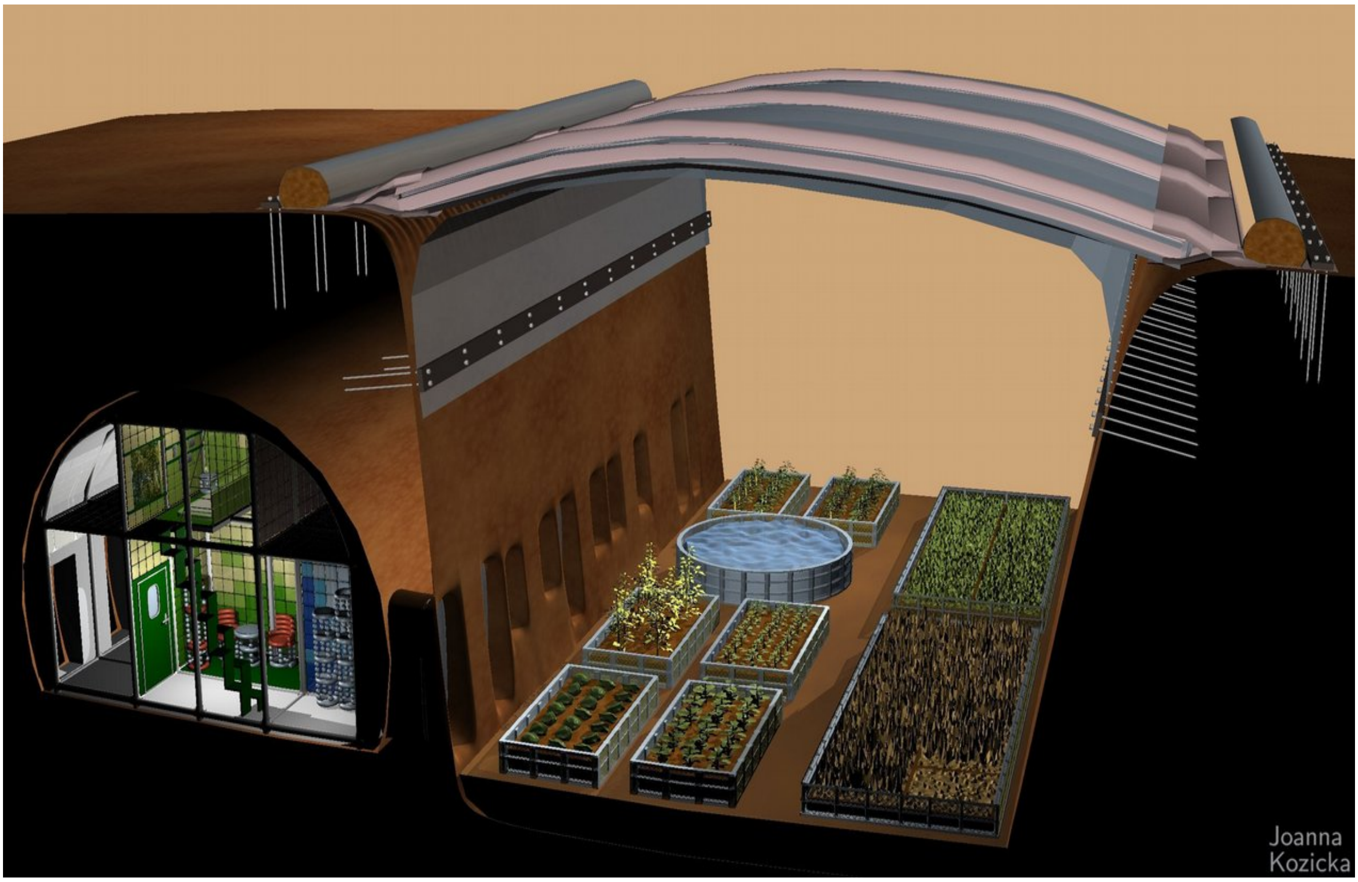
Foils of both of the coatings should be made from a foil of a chemical structure consisting light elements. They should protect the structure against radiation pollution. To protect the agriculture better, there could be a demron curtain spread over the upper coating. As demron is not transparent, such curtains should be used temporarily only, when required to protect the habitat against the highest danger.

The entrance to base is made from metal modules with airlocks. There could be used for the purpose empty ships that were used to transport from Earth elements and vehicles to built the base. There are garages built near those modules. They are hangars made from firmed pneumatic construction, covered with a coating protecting against Martian dust.

Interiors

The base consists of two types of space: well illuminated, spacious, open hollows, and well protected against radiation underground tunnels. The first type of space is suggested for orangeries for plant-growing, the second one—for permanent presence of people (Pict. 8.7).

There are cultivators layed in orangeries, made in a form of oblong, not very deep boxes, filled with soil to grow plants. The boxes are made from pneumatic frame, which may be firmed with resin, pumped diaphragms or ropes. Spaces between beams of the frame are closed with membranes and nets. Smaller cultivators are to grow vegetables and fruit bush, larger—to grow grains. Cylindrical boxes may also serve as water magazines, fish ponds, and even as swimming-pools. A possibility of swimming and playing in water would really enhance the general comfort level at the base. Window and door openings cut out in the slope would give a view at green gardens from residential and working parts of the habitat (Pict. 8.8).

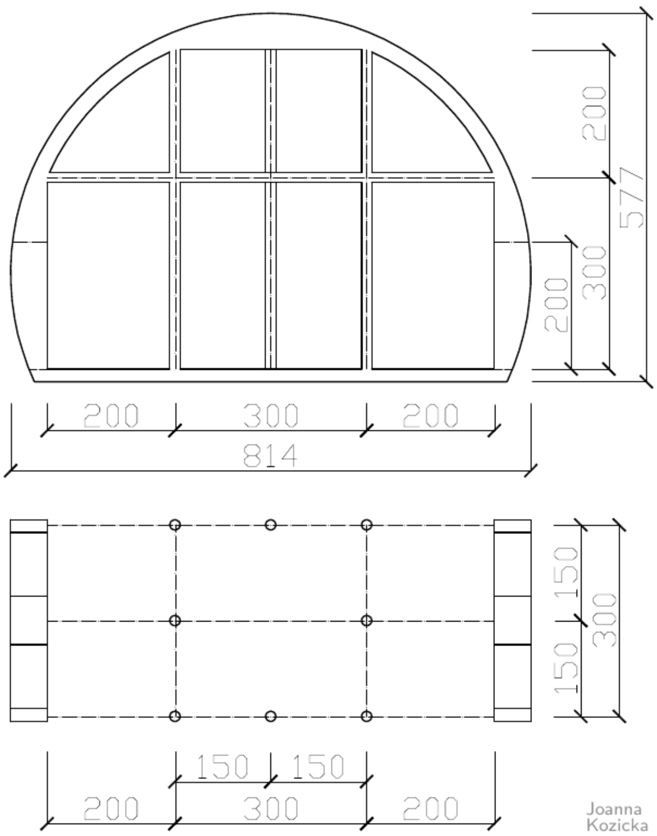


Picture 8.7: A close view of the fragment of one of the gardens at the base, with visible plant and grains cultivators, and a water cistern

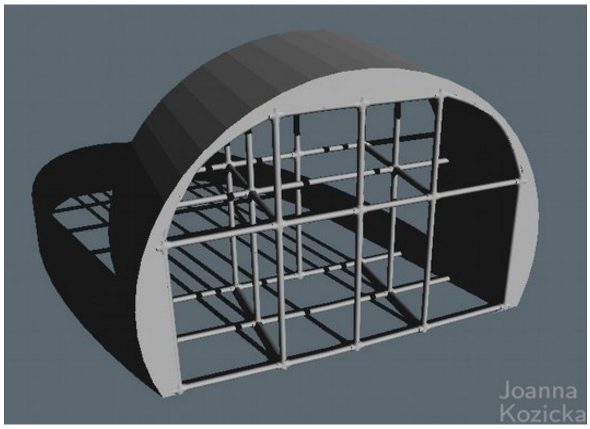
Picture 8.8: A view from the garden at windows of the habitat, with a view of the insides

In the manageable space there would be installed rows of SMP modules (Pict. 8.10, 8.11). Such a module would function in two ways: to straighten the curves of the tunnel vaultings, making it easier to manage the insides with the use of repeatable elements; it also creates a frame to install flexible divisions. It is assumed that the module's measures are: 814 cm x 577 cm x 315 cm, and its shape is adapted to the cross-section of the tunnel, as it is shown in the Pict. 8.9. Horizontal beams and bars divide a module into six parts: three of them down, and three up. The lower parts are about 3 m high, and the upper parts are 2 m high—in the highest spots. There are the main manageable parts on the ground floor of such a module. Two side parts of the upper floor are designated as fixture ducts, and there could be a low entresol created in the middle, or a low upper floor, or a high ceiling for middle parts of the ground floor. There is anticipated a communication duct in one of the sides of such a module, ground floor, and the other side part, together with the middle parts, are to become residential, recreational, and working areas. Such an SMP module is 3 m long in its axis. The measures are counted to assure the right height of areas for people, to create a comfortable communication duct, and to create comfortable rooms, which are functional, and at the same time possible to differ one from another. There are two holes in the side walls of each module: they may be used for doors to be installed, windows, or to install a wall unit in it, or a niche with a seat. The hole's measures are default—1 m x 2 m.

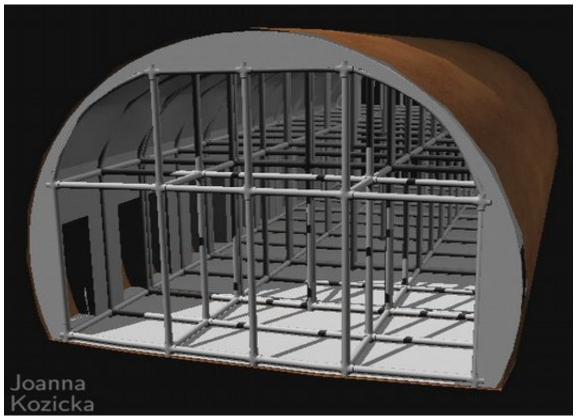
SMP module is thicker on the border sides, to touch safely the tunnel walls, and to assure its fixed position and shape. An inside structure is built from a frame made from tubular elements, which cross each other as upright posts and joists. This is a frame which stabilizes the shape of module. There are symmetrically set smaller tubular elements fixed permanently with the construction of module. There are holes planned to fasten screws in them. Those tubes are also inserted into thick walls of the module, in analogical places. They make it possible to fasten to them wall and floor elements, as it is shown in the Picture 8.12.



Picture 8.9: A cross-section and a projection of SMP modules with exemplary measures



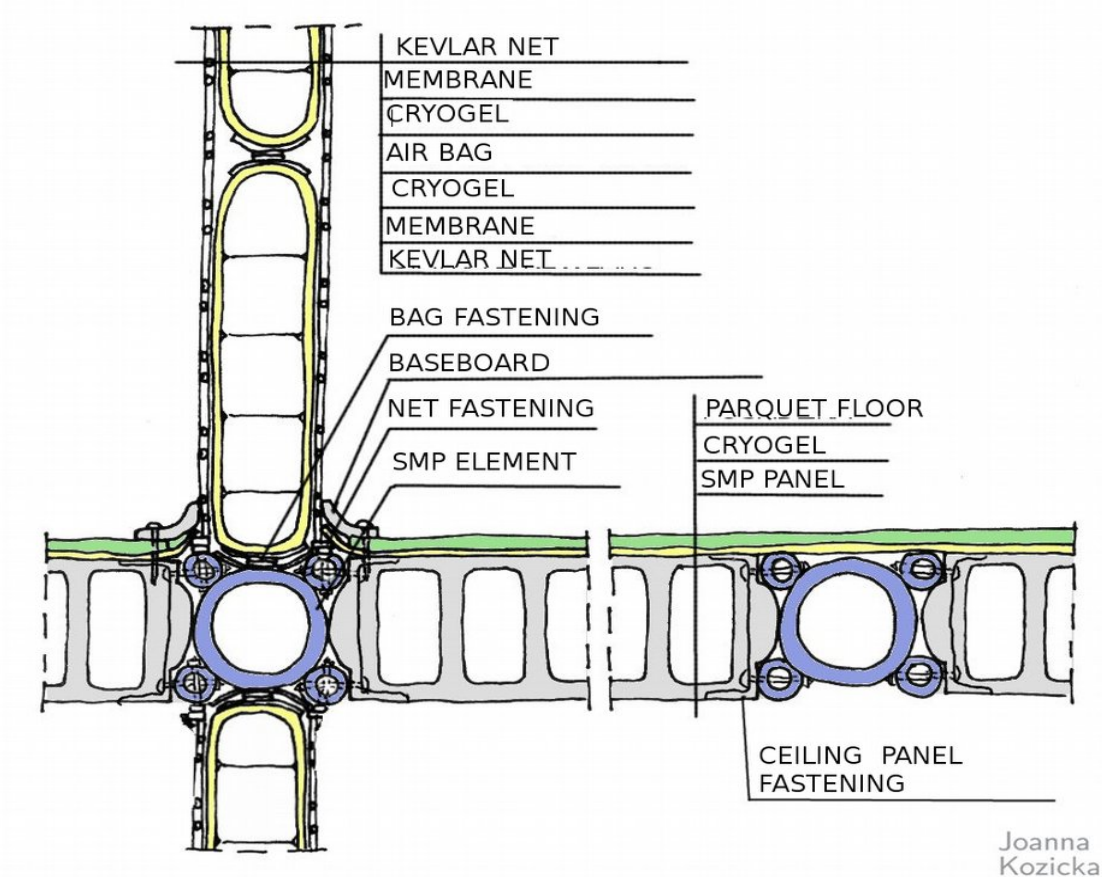
Picture 8.10: A single SMP module



Picture 8.11: A row of SMP modules set in a tunnel

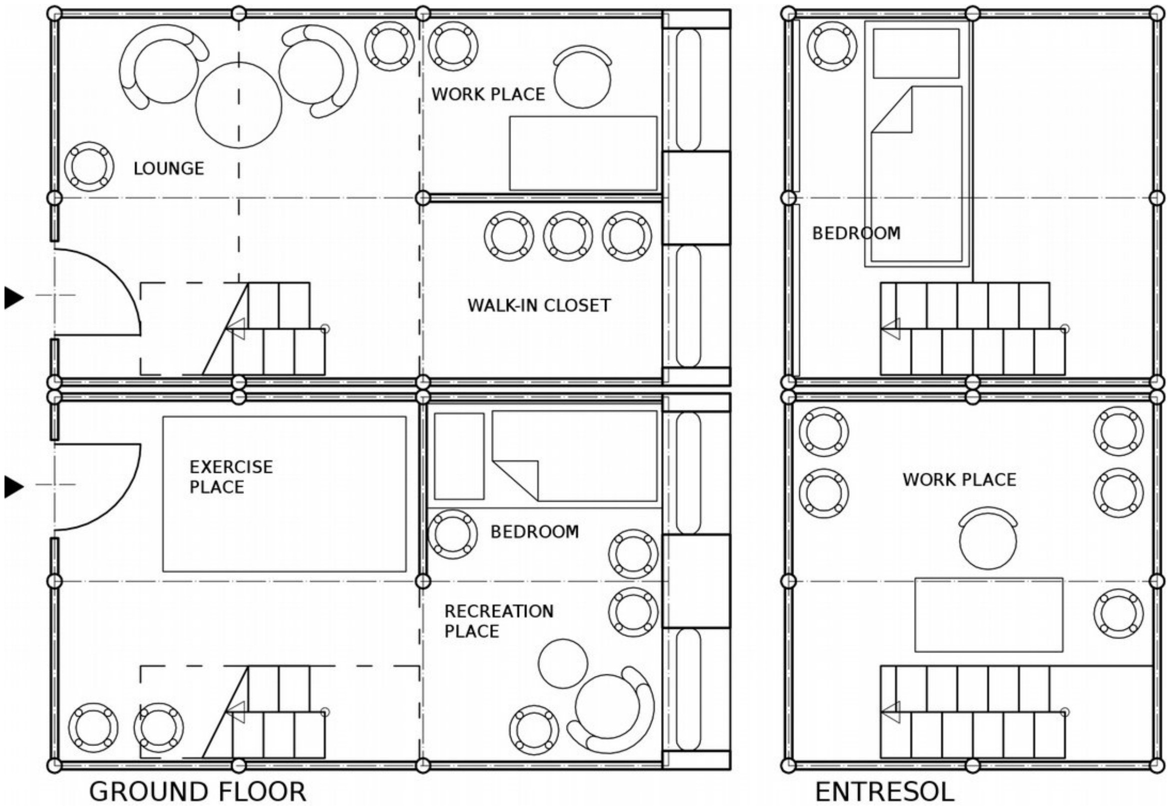
All of such tubular elements are woven from Kevlar fibers. Large tubes are sewn with smaller ones to create one structure, and next they are covered with Shape Memory resin, creating a durable composite. That way an even structure is created, which may be packed tightly for the transportation from Earth to Mars, and easy to unfold *in situ.*

There are planned two kinds of inside divisions in the base: SMP and pneumatic. SMP divisions create large panels filling the whole space between SMP frame elements (after expanding them). They are to be used in places where greater durability of a division is required, and in places where an additional element would be installed (a door, or any special kind of element). Thus, some of them create a continual element, and some of them have modular holes. Continual elements would be mostly used as ceiling panels. Panels with doors are shown in the Picture 8.19. It would be best, if elaborated here elements had SMP fillings of low density and a good acoustic characteristic, and they would be covered with rigid SMP layer on the outside part (possibly with additional reinforcement). There should be chosen plastic materials with a similar temperature transition.

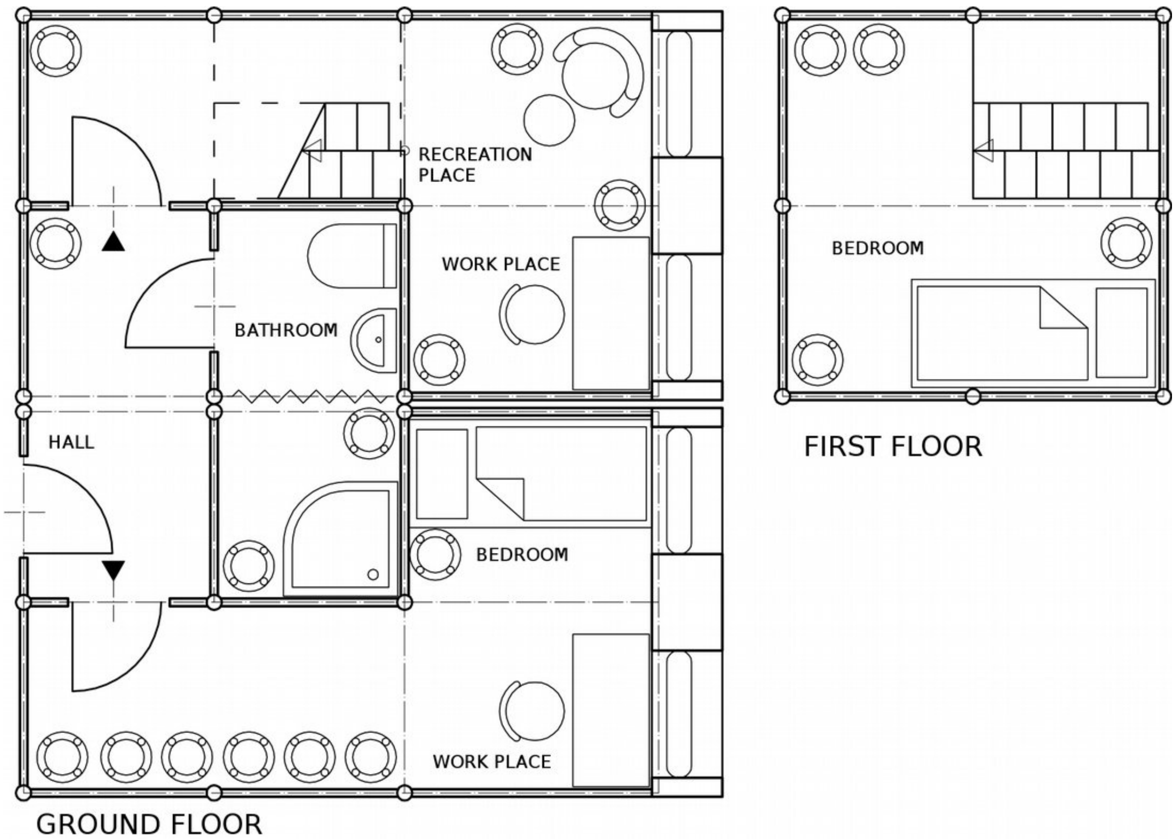


Picture 8.12: A detail of the fastening of SMP pneumatic division walls and SMP ceiling panels

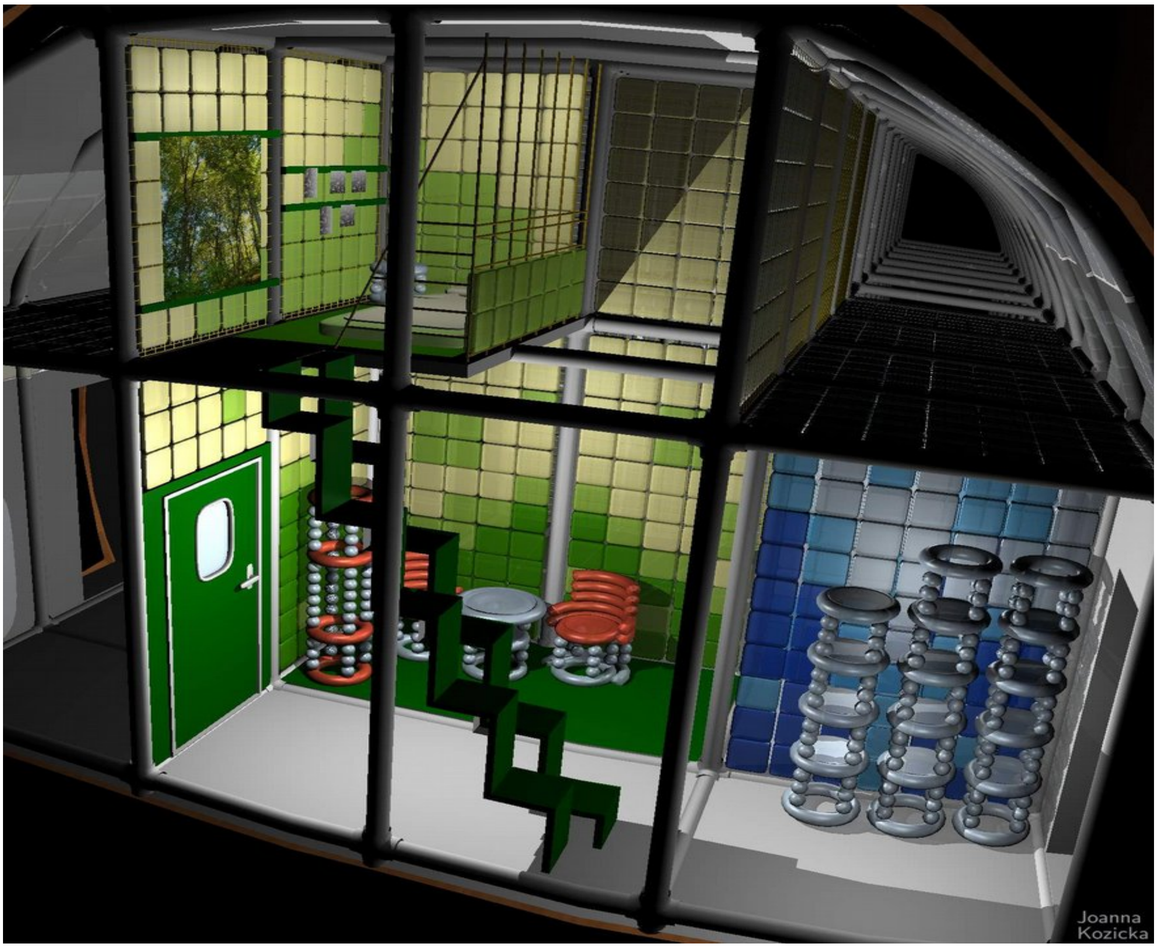
The second type of divisions used in base would be pneumatic divisions. They are built from pumped square bags, e.g. 24 cm x 24 cm. Every bag should have the inside hardening to keep its thickness relatively constant. A layer of flexible aerogel (e.g. Cryogel) would create the acoustic barrier. There would be clip-buttons on the edges of bags to connect the elements so as to create a larger element. It is suggested that the pneumatic bags would have different colors to build variable rooms, with different wall patterns. To reinforce walls there would be Kevlar nets used, fastened with screws to small SMP tubes in modules (Pict. 8.12). When a division is planned to fill the space between frame upright poles partially only, it may be reinforced with a string attached to hooks. It would make possible to create an openwork division and hangers for clothes, towels, pictures, notes etc. A string would allow habitants to perform almost unlimited creativity while building architectonic functional and decorating elements; strings would also expedite the installation process.



Picture 8.13: The interior arrangement of the private rooms in the base, projections of two adjacent rooms.



Picture 8.14: The interior arrangement of the private rooms in the base, projections of two adjacent rooms with a Jack and Jill bathroom.



Picture 8.15: A private room with entresol visualization

Picture 8.16: A small sitting-room in private quarters

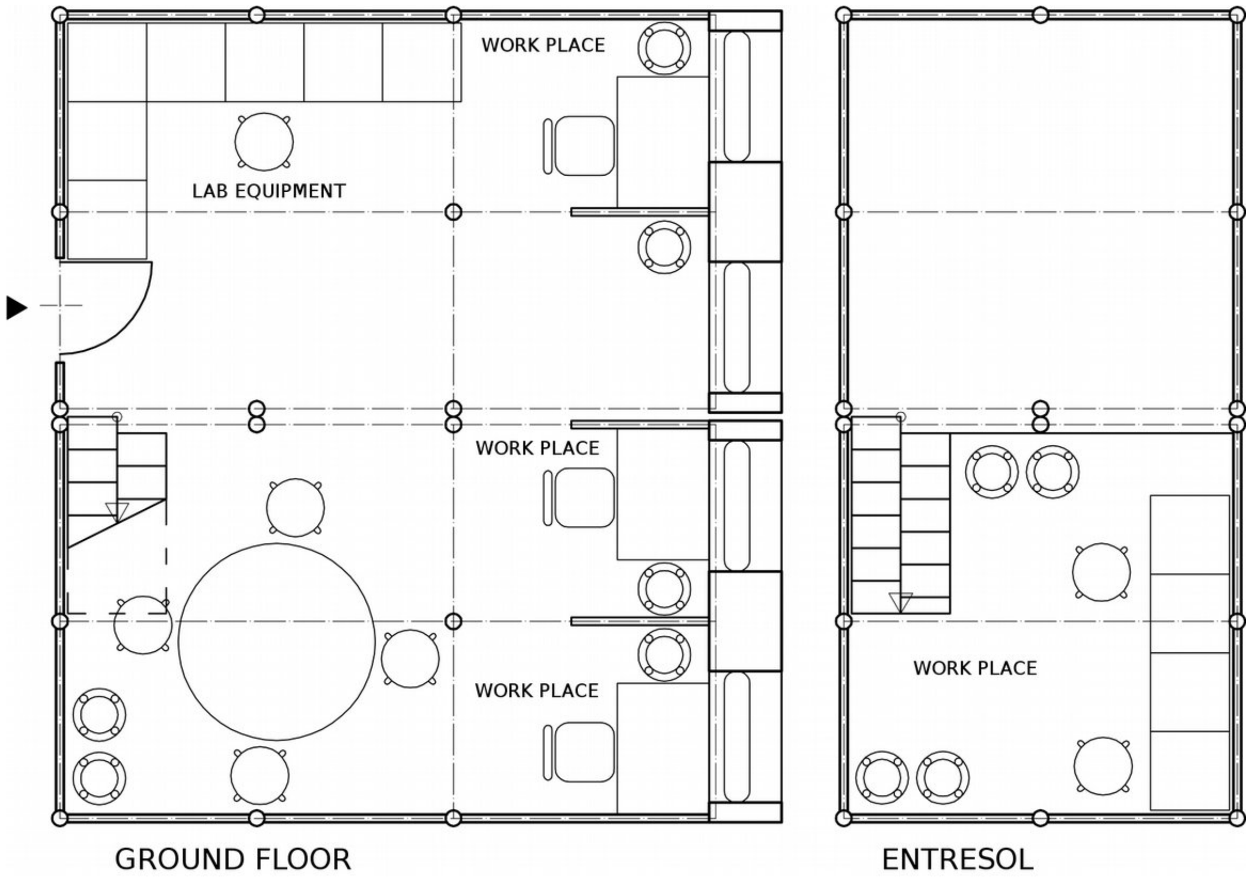
Picture 8.17: A bedroom on entresol in private quarters

Floors would be created with lower parts of a SMP module on the ground floor, and with installed SMP panels on the upper floor and entresols. The side parts of the upper floor, those creating fixture ducts, would be covered with colorful pneumatic barriers, visible from the ground floor as a ceiling, as there would be no heavy parts in those places, and the ceiling would be colorful. A good acoustic floating-floor effect would be gained with a Cryogel layer on the floor. It is a very expensive material, however, very light and flexible, that is why it is suggested for Martian base, and among other advantages—its use would lower transportation expenses. Cryogel would protect effectively the insides of Martian base from the effect of warm air escaping to the surrounding rock-mass. There are suggested color floor-coverings made from plastic, e.g. from PCV popular on Earth, for working places and for communication ducts, and soft floor-coverings, nice in touch fabrics, for residential rooms, to enhance the living conditions.

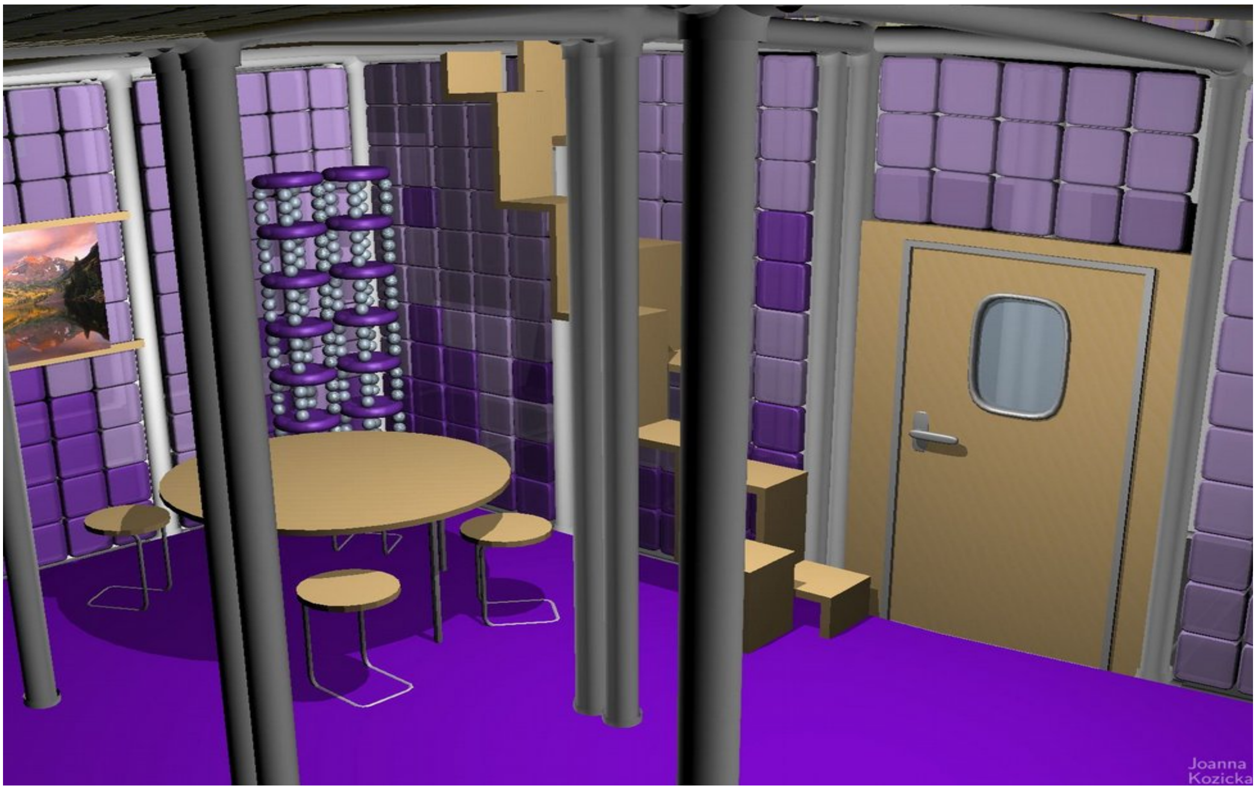
The planned habitat space is flexible. Thanks to the use of repeatable elements, which may be connected in different configurations, the insides may be arranged and re-arranged many times. There are horizontal projections in the Pict. 8.13, 8.14, 8.18 and 8.21, showingdifferent arrangements of the space in a habitat built from 2-3 SMP modules; there are private rooms, a laboratory, and a mess. The rooms may be one-storey, with an entresol, or two-storey; they may create one large open area, or to be divided into annexes with some divisions. There are many possibilities, and there are only some of them shown in the pictures.

Pneumatic bags of divisions walls, pneumatic furniture, and unfolded furniture coverings are planned in different colors. Thanks to the wide range of used colors for the interior design elements, there may be created insides of different color moods. An example of such a use of colors in a private room in the Pict. 8.13 is shown in the Pict. 8.15. There is on the ground floor a small sitting-room, where a visitor may be invited, or where there is enough room to relax in an armchair, to read a book (Pict. 8.16). Next, there are two small annexes: one is planned as a working-area, the second one as a wardrobe. There are stairs leading to a small entresol. This is a bedroom, with a pneumatic mattress, a nightstand, and a place for a family picture and a landscape poster (Pict. 8.17).

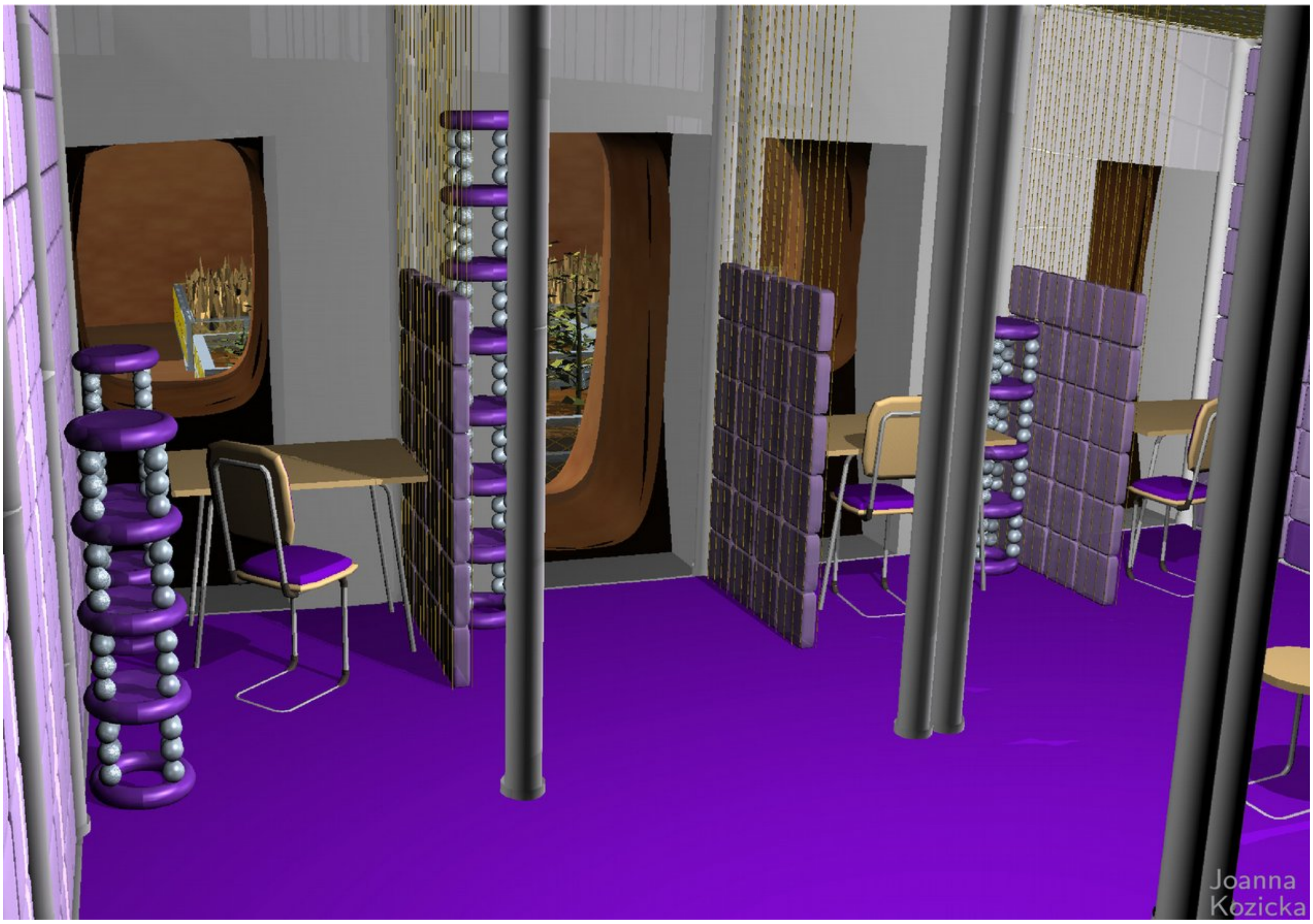
There are shown visualizations of working areas in the base in the Pictures 8.19 and 8.20, e.g. a laboratory. There are separate work-places and a conference-table, and to work in groups. Individual work-places are located near windows with the view of gardens, what would enhance the moods of people during their work. There is a separate area shown in this projection, in the Pict. 8.18, planned for specialist equipment. There is a small store room on the entresol shown and additional, temporary work-places.



Picture 8.18: Interior arrangement of a laboratory in Martian base, projection



Picture 8.19: Laboratory in Martian base, a work-place for a group of people



Picture 8.20: A laboratory in Martian base, individual work-places with a view to the garden

Means to ensure comfort in the base with the help of architectural tools

Socio-psychological problems may be decisive in the success of Martian missions. That is why there are taken precautions to achieve the highest possible psychological and physical comfort level in the concept project of Martian base, to achieve the most human-friendly habitat. There are elaborated advantages of such a habitat, and what architectural tools are used here to assure the highest work level, living conditions level and recreation in the base.

1. Sense of security
   - (a) resistant, air-tight construction;
   - (b) good protection against Sun and Space radiation;
   - (c) a very good protection against weather conditions, meteors and any other mechanical damages;
   - (d) there are at least two evacuation ducts from each part of the base;
   - (e) a failure of one element does not compromise the existence of the whole base;
   - (f) there are many entrance to the surface from the habitat;

(g) building materials restrict fire hazard: rocks, SMP, fire-proof plastic foils, aerogel;

(h) BIO LSS in orangeries create the habitat's independence from food delivery from Earth.

2. Large manageable area:

   (a) large, spacious habitat, protecting from the claustrophobia, sense of tightness and discomfort;

   (b) large area may be divided in different ways, creating visible divisions between different zones;

   (c) possibilities to own private, comfortable residential cabin.

3. Private area:

   (a) a comfortable private cabin;

   (b) habitants have at their disposal some private, separated area;

   (c) in a large base such private area may be considerable big (here, in this project, it may be 15 m^2 to above 20 m^2, when there is an entresol added).

4. Deliberative zone divisions:

   (a) residential and working area divisions;

   (b) silent zones in separate underground tunnels;

   (c) clear private and public area division;

   (d) at least several residential tunnels to let conflicting parties live separately;

   (e) the main communication ducts, connecting residential and working area, should function as recreational area to diversify the way home, and giving natural opportunities to meet people.

5. Good acoustic conditions:

   (a) more noisy functions should be separated from silent ones: residential, working and recreational functions are located in separate tunnels;

   (b) fixture ducts are led in closed chambers in the corners of tunnels creating separate maintenance area, divided acoustically from the residential area with walls built from pneumatic bags, isolated additionally with Cryogel;

   (c) separated maintenance area as separate rooms, which are possible to built only in a large Martian base;

   (d) 'straightening' of curves allows avoiding arched ceilings which carry and return sounds in a specific and noticeable way;

   (e) SMP divisions may have a slightly uneven surface to mute sounds;

   (f) reinforcing nets of division walls create their uneven texture, which assures a better acoustic conditions of the insides.

6. Good illumination:

(a) natural illumination of the insides assured in orangeries with transparent and translucent roofing, and indirectly—in habitable area with the light from orangeries via the doors and windows;

(b) thanks to mirrors focusing and reflecting the sunlight into orangeries natural illumination is strengthened;

(c) all of the rooms designed for permanent stay may be illuminated with natural light because of the windows in the slopes of orangeries; communication ducts are the only places here with no access to windows, as it seems that this function does not require it;

(d) artificial light may be introduced in any place of a room, because the cables are to be led in the corners of tunnels, and they are easy to be introduced into rooms through the pneumatic bags of divisions.

7. Ergonomic manageable area:

(a) the distance between the upright poles, bars, roof beams and SMP walls allow creating rooms similar in their size to the rooms built on Earth, and concerning ergonomical human needs;

(b) larger rooms have SMP modular pillars installed inside to create supporting for people having difficulties with moving in lower gravitation conditions; additional supportings may be built from other elements of interior design;

(c) provided stairs are steeper than on Earth due to different gravitation conditions and, what follows, different way of moving legs, and lower strength required to go up.

8. Contact with nature:

(a) visual contact via the windows in habitable area;

(b) possibility of walking on the garden paths, among cultivators;

(c) possibility of looking after plants, collecting crops, etc.: work or recreation;

(d) communication ducts in pneumatic transparent tunnels may lead through some of the orangeries to walk in the greenhouse without the need to be especially cautious for bacteria, microbes; it may be a nice element on the way to the work-place and back;

(e) water is an element of nature; water tanks and watching fish in them may also enhance a desirable contact with nature.

9. Flexible habitable space:

(a) every tunnel is filled with modular SMP structures creating frames to divide the space differently: rooms, niches;

(b) tunnel space may be left not divided (poles only), or divided into separate rooms;

(c) there may be planned high-ceiling rooms (public places mostly), or low-ceiling cozy rooms (private cabins mostly); there may be built second floors or entresols;

(d) openings in the side-walls of modules may be enlarged to install windows and doors, or they may be left blocked and used to install wall units or niches for seats;

(e) SMP modules are adapted for SMP panels to be installed in them, and divisions made from pneumatic bags and Kevlar nets; those elements are in different colors and they may be arranged in different configurations;

(f) thanks to drilling technologies there may be built additional niches, to build a bathroom or a handy store room;

(g) division walls are light and simple to install, so any habitant may build interior elements fast and easy, rebuild them, and arrange the manageable space according to various needs; the coloration of a room may be changed in the same way;

(h) unfolding and pneumatic furniture (similar to that shown in Pictures 8.15 and 8.19) is simple to arrange and re-arrange;

(i) an SMP module of the wall with a door may be installed in different places.

10. Possibility to personalize space:

(a) color bags for division walls, and easy to replace furniture coverings, allow for the wide choice of colors for each private and public place, according to the needs;

(b) light portable elements of interior design may be arranged according to personal needs;

(c) functional arrangement in private cabins may be adapted according to personal needs, because of different wall divisions installation, entresols, and furniture arrangement;

(d) bars attached horizontally to the SMP frame make it possible to attach them on different heights to pin family pictures to those bars, posters, notice-boards, souvenirs, etc.

11. Diversified life environment:

(a) flexible, adaptable interiors;

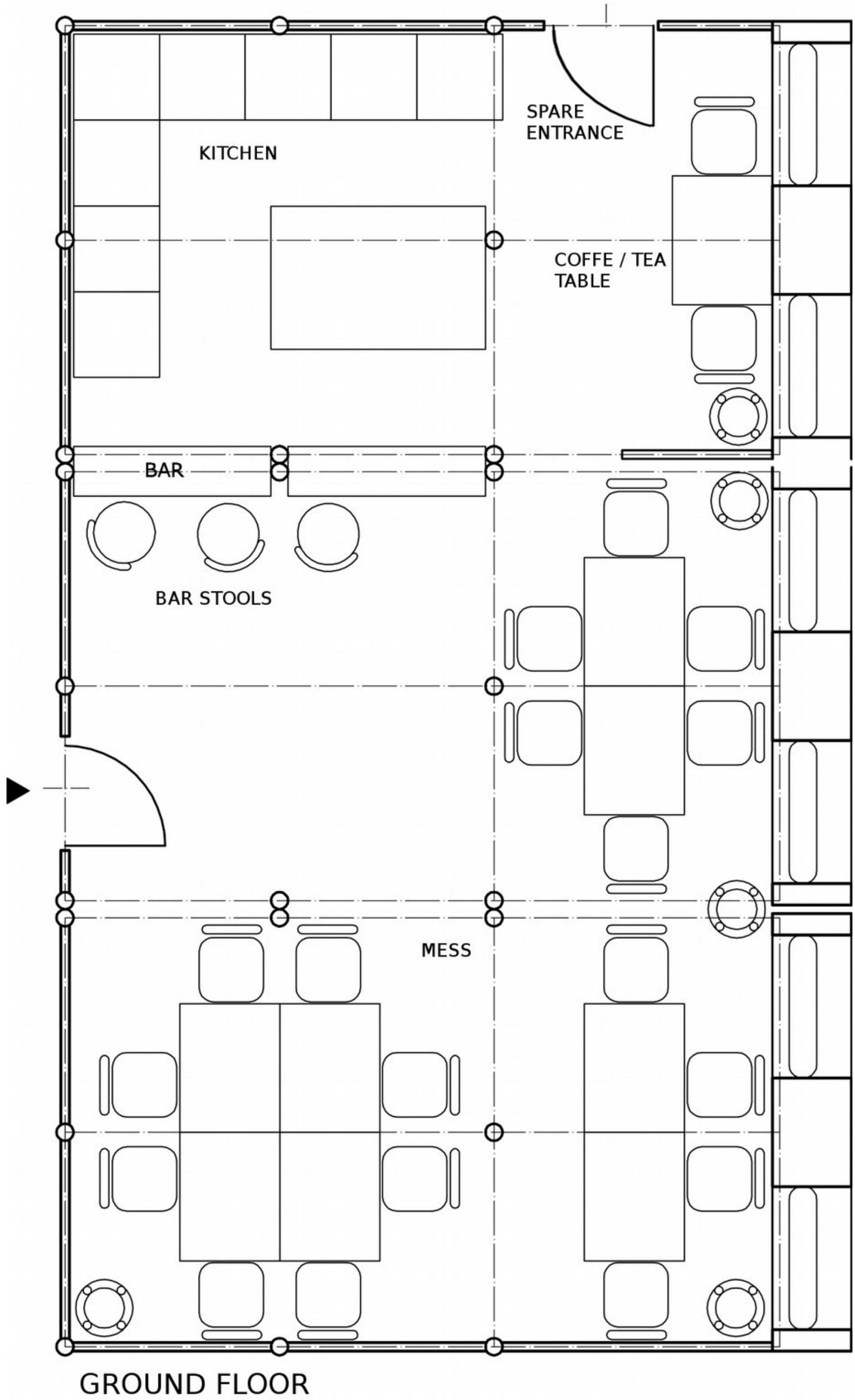
(b) variability of interior coloration;

(c) different interior design elements, possible to built because of modular elements, e.g. pneumatic bags to build walls, ceilings, low walls, decorating elements, pneumatic sphere and torus to build armchairs, tables, stillage (as it is elaborated in Chapter 6.4.2);

(d) variability of illuminance: natural illumination changing according to part of a day, artificial illumination possible to install in different configurations;

(e) orangeries and tunnels in different length, managed differently;

(f) thanks to orangeries, stages and phases of nature may be observed.



Picture 8.21: Arrangement of the mess for about twenty people, with an open kitchen, projection; tables in modular sizes, which may be arranged together in different configurations

9 Conclusions

Manned mission to Mars is a particular case of the space-flight due to its long-term duration. A human factor becomes here as important as technological problems are. The author argues that people cannot stay for over two and a half years in a cramped and uncomfortable capsule (as among others a NASA outer-space scheme states). A human-friendly habitat seems crucial here. Some researches of human behavior in ICE show that where there are more than a few people, the lower level of conflicts is observed. Therefore, for a bigger crew a larger living space should be designed–Martian base. **The extreme Martian conditions require a specific architectural design.** Considering this, the author has decided to perform several comprehensive analysis relating to Martian architectural designing. The conclusion of her researches are that **the current knowledge about Mars, along with contemporary building technology, enable designing of several different human-friendly habitats on the Red Planet**. The evidence to support the author's statement are the architectural models presented in this dissertation. **Some architectural implements may positively determine a higher physical and psychical comfort of the occupants of the extraterrestrial base**. The concept project accomplished by the author here shows that relatively low expenditure is enough to establish a safe construction, which is at the same time aesthetic and human-friendly, with the possibility of changing arrangements and expanding, due to the actual needs.

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