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Low-cost solutions for Martian base

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Abstract

Technical and architectural problems of a Martian base have been arised in many publications. Usually there is one solution described in detail or general classification is presented. In this paper, a recognition of low-cost solutions for Martian architecture is analyzed. The overview through various building techniques based on previous concepts of extraterrestrial architecture is summarized. Several solutions taking advantages of the shape of terrain, aiming for cost decreasing of human settlement on Mars are proposed.

Keywords: Design; Extraterrestrial architecture; Mars base; Habitat

1. Introduction

Scientific research in extraterrestrial architecture deals with two problems: how to build a human habitat and how to do it in an affordable way.

Many approaches to conceptually design a planetary base, like: Benaroya et al. (2002) or Petrov (2004) etc. are known.

Each solution deals with the problem in a different way, providing several simple instructions to follow. Special conditions for extraterrestrial extreme environment must be fulfilled:

- living space must be hermetic; Martian atmosphere is very thin and is mainly composed of CO_2,
- construction must be stable, tough and resistant, to be safely inhabited,
- assembly must be simple, with as little as possible points of failure,
- human factor must be thoughtfully analyzed, as Mars is a distant planet and living area is restricted to base interiors.

The methods of lowering cost of Martian base construction are specified below. Some of them have been applied in previous architectural concepts (examples are adduced in brackets) and the other are new:

- use light structures easy in transport from Earth (Benaroya et al., 2002),
- use local materials (MacKenzie, 1989),
- employ underground natural formations (Kokh, 2002a),
- employ shape of the terrain in the construction,
- use the most optimized technologies for certain elements/parts of the base,
- habitable space should maximize usage of available volume.

All building techniques require supply from Earth, therefore decreasing transport volume and weight is desirable. This can be accomplished in two ways. First by transporting light deployable structures, second by sending one manufacture that produces building materials using local sources (*in situ* material utilization). First solution is applicable for small bases, while second is suitable for bigger ones (or planned to further development). Optimizing usage of available volume results in smaller distances between habitable spaces and shorter communication routes. Thus construction costs are lowered and quicker evacuation in case of danger is achieved. Natural slopes

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of terrain formation can act as the walls of the habitat, afterwards the size of artificial construction is decreased along with the price of the investment. Underground habitats require special machines to drill holes in the ground, instead of manufacture that produces building materials. Building Martian base with only one technology allows to focus on this construction technique, decreasing points of failure. However, the base consists of various elements, like: walls, windows, covers, airlocks, etc. Each element has different requirements. Building them all together with single technology is not a cost-effective solution and can give poor results, since different technology suits best each element. The solution proposed in this paper is to find the best technology for each type of elements and focus on the improvement of it.

2. Technologies

Several building technologies adaptable in Martian environment are considered and summarized in the following: metal constructions, pneumatic structures with anchorage, brick and concrete, soil blocks and underground tunnels.

2.1. Metal constructions

Metal constructions are most reliable in the extraterrestrial application and have been proved many times in extreme space conditions. Until 2005 only metal was used for space habitats (i.e. space stations, space shuttle and lunar Apollo modules). Metal constructions are strong, tensile, puncture and tear resistant, that's why they are used in different Mars base concepts: Kokh (2002b) or Griffin (Benaroya et al., 2002). However, they are heavy and compact packing is difficult, thus their price in extraterrestrial missions is high.

2.2. Multilayer membrane structures with anchorage

Application of multilayer membranes for pneumatic structures on Mars seems to be of great interest. The construction can be supported only by internal atmosphere under pressure (which must be produced for people to breathe anyway). Different Martian (and lunar) base concepts deals with inflatable constructions: Vanderbilt et al. concept (Benaroya et al., 2002), Sadeh and Criswell (1996), Hublitz et al. (2004). Transparent membrane structures provide natural lighting inside the habitat. It can largely influence psychological comfort. Terrestrial architecture has adopted light textile and film structures since 1950s, but they are still perceived as "new" technology solutions. The quality of plastic flexible materials for buildings still improves. The multilayer elastic structure has been developed for inflatable space station in NASA laboratories. Currently it is adopted for Nautilus space hotel built by Bigelow Aerospace (Covault, 2004). Two categories of membranes are considered: with high overall material strength and hermetic ones.

List of membranes with high strength utilized in architecture includes: Sheerfill Architectural Membrane (Birdair), Tefzel ETFE (DuPont) and Teflon FEP (Foiltec). Sheerfill is a teflon-coated woven fiberglass glazing system, where fiberglass substrate provides high mechanical strength and PTFE coating gives chemical and weather resistance. The lowest working temperature is −73 °C (usable near Martian equator), however application of PCTFE will make it suitable to use in −270 °C (usable on whole Mars, but less mechanically resistant). It lets to pass through about 25% of light, with UV filtered out. Tefzel and Teflon are thin, highly transparent (nearly 100%, including UV) films. Ultraviolet light is not suitable for living space of the habitat, but is recommended for agriculture modules. They have very high weather resistance, are easy to clean, have excellent mechanical strength and are reliable against cracking and abrasion (Robinson-Gayle et al., 2001). Between two layers of Teflon a crystalline silicon photovoltaic solar modules can be encapsulated to provide extra energy supplies for the base. It seems that heating foils between two elastic films can reduce material brittleness and allow habitat heating.

Polyimide is a fully hermetic membrane; no gas or liquid can pass through it. This plastic film resists UV radiation and −270 °C, and has clear transparency. It is tinted with orangebrown color, and colorless version is under development. Due to its special properties Polyimide has already been designed for space application (Moore and McGee, 2001).

The membrane structure can be supported only by inside atmospheric pressure, however inflatable membrane should be attached to the ground. Different types of anchorage are presented by Gyula (1977). An interesting solution for supporting a membrane is a domelike Hoberman expandable structure (Hoberman, 1997). Demron membrane provides antiradiation shelter, and can be combined with other membranes (Marcy et al., 2004). The manufacturer of Demron is Radiation Shield Technologies (www.radshield.com).

2.3. Brick and concrete

The surface of Mars is covered with fine red dust of thickness exceeding tens of centimeters. Martian soil is confirmed to contain clay minerals (Bibring et al., 2006, Matijevic et al., 1997). It can be used like terrestrial clay to produce bricks and mortar (Stoker et al., 1991). Some additions, like fibers, would strengthen such blocks. Hand-operated press also would improve them. To recycle water, bricks should be fired in a hermetic kiln (MacKenzie, 1989). Mortar requires water in its liquid form, and building with it is possible only under sealed cover. If bricks are specially shaped it is possible to match one to another tightly. Masonry construction works properly when compressed, thus before pressurizing it with breathable atmosphere it must be covered by a balast (e.g. Martian regolith layer) to prevent explosion. Petrov (2004) proposes

11 m regolith layer for 60 kPa of internal pressure. But the compression can also be provided by strong textile or dense net anchored to the ground. Petrov explains that pitched-brick vaults and domes are the most attractive solutions as they do not demand boarding and it is easy to construct them.

It is presented by Boyd et al. (1989), that concrete (called *duricrete*) can be produced on Mars using simple methods as based on simulations made with imitation of Martian soil in Martin Marietta company in late 1980s. Martian soil consists of gypsum which can be calcified. Addition of lime will strengthen duricrete making it comparable to portland concrete (Boyd et al., 1989; Stoker et al., 1991). However, concrete structures require water and boarding, which is problematic on Mars.

2.4. Soil blocks

Martian regolith is the most available resource on the planet, and there are several ways of using it. Stone blocks can be cut to small elements like bricks. It appears to be the most obvious method, which was applied by many cultures on Earth, e.g. the Egyptians (pyramids), the Mayas (temples), the ancient Zimbabwe (castle) and in Europe in Middle Ages (cathedrals). However, it is energy consuming and other methods should be analyzed. Khalili (1999) has developed simple and not expensive building method (called *superadobe*) which requires only a mud, small quantity of cement and low-cost wire for reinforcement. Soil inside long bags is put in a dome structure, with barbed wire between. The superadobe is strong enough to withstand an earthquake. Using liquid water is possible only in sealed space on Mars, thus resin could be used as a water replacement in this case. NASA has analyzed the epoxy ICI Fiberite 934 (Kim et al., 1998), which can bind Martian regolith and increase radiation shelter simultaneously. However resin will have to be brought from Earth.

2.5. Underground tunnels

Gertsch and Gertsch (1995) analyzed different methods of making underground tunnels on Earth to be adapted for use on Mars. The loose soil can be excavated and compact ground can be drilled. The most common method called *drill and blast* requires a heavy drilling machine e.g. Tunnel Boring Machine (TBM). Its transport will be expensive. However once the machine gets to Mars it can be used to build the whole base. Thus usage of such TBM can be considered for bigger bases, where its weight will be smaller than weight of transported goods in other solutions. Long tunnels with smooth walls and good muck fragmentation may be achieved which makes excavating easier (Kuczyk, 2002). This method requires explosives. They can be imported from Earth. Mars may provide the appropriate raw materials to manufacture explosives. This is an area of research that deserves increased attention (Gertsch and Gertsch, 1995).

3. Mars base concepts

3.1. Tunnel Outpost

Steep slope formations occur on the Mars surface in following types: *rupes*, *scopulus*, *chasma*. The picture of such natural structure is shown in Fig. 1. Similar terrain forms on Earth are used for human settlements. Natural caves were used by human race 1000 years ago, then techniques for drilling tunnels inside rocks were developed. Ancient

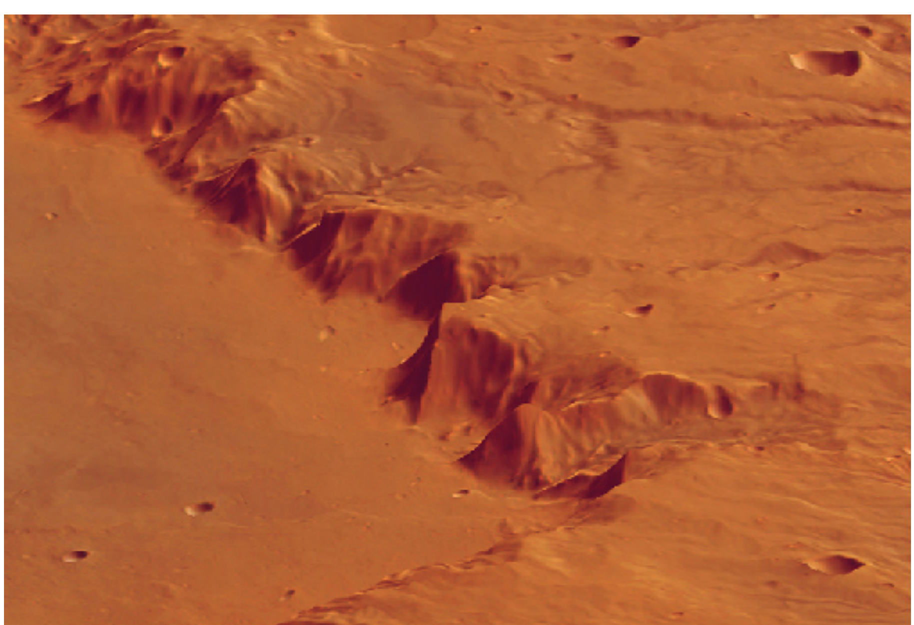

Fig. 1. Steep slopes near Huygens Crater (Photo: ESA/DLR/FU Berlin (G. Neukum)).

Fig. 2. Cliff dwellings near Santa Fe, a postcard.

people in Asia Minor (e.g. Jordan) built shelters near slopes and sculptured ornamental portals that lead into cave temples (e.g. Petra). Indians from Mesa Verde (U.S.A., Colorado) lived inside cliff dwellings (Martin, 2003) (Fig. 2). Some cave houses on Earth are still inhabited by people (e.g. Cher Valley in France).

Frederick (1999) and Kokh (2002b) proposed to use lava-tubes on Mars (and Moon as well) to locate first human outposts. Lava-tubes are natural volcanic formations which occurrence is possible on Mars (Carr et al., 2001). Their location may be inappropriate for situating a Martian human base, moreover providing natural lighting is problematic.

The Tunnel Outpost concept presented in the paper (Fig. 3) proposes an alternative to using lava-tubes. Occurrence of natural vents in Martian cliffs is not confirmed, so only artificially made ones are considered. The advantage of such solution is that it allows an easy access to sunlight, where no extra periscope-like windows are needed (Kokh, 2002b). Windows are cut in the slope along the drilled tunnel. The window insulation can be done with transparent inflatable ETFE-PI cushions. Insu-

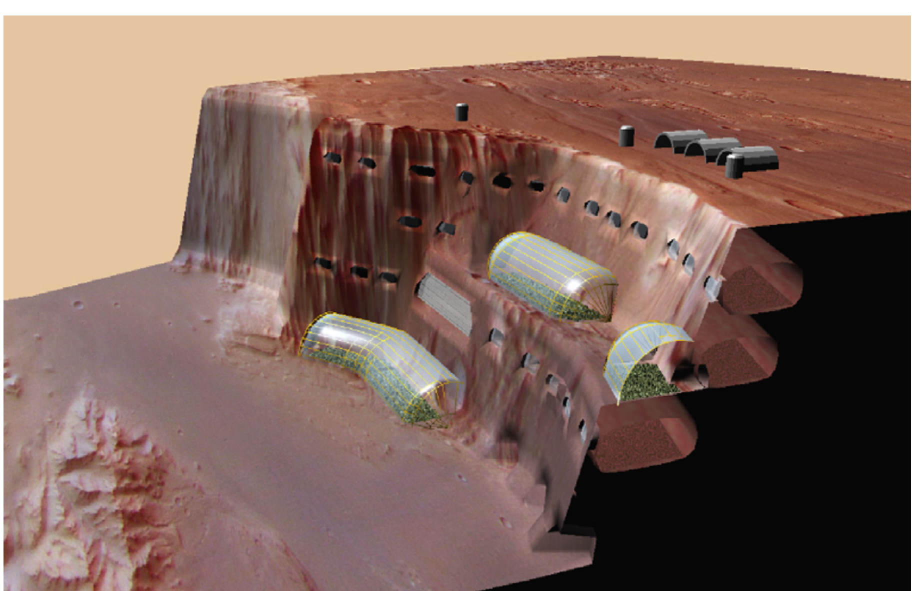

Fig. 3. Tunnel Outpost concept.

lated water–ice walls for bigger holes can be used where clear transparency is nonobligatory. Pneumatic modules are proposed for agriculture or extra habitable spaces. They may be anchored at the foot of the cliff or on a shelf-rock. Half-tube metal barracks and hollows in the ground at the foot of the cliff can act as garages and certain magazines which do not require breathable atmosphere. Metal modules with airlocks are chosen as the safest. They are mounted at the peak of lifts which provide communication between all floors of the base inside the hill.

3.2. Terrace Village

Valleys (*vallis*, *fossa*), hills (*mensa*) and certain mountains (*montes*) on Mars have flat slopes, like shown in Fig. 4. Terrain formations with such slopes are often used as terraces on Earth. Advanced technologies or highly qualified workers are not required in the case of terraces construction. Different building techniques have been developed thorough the history. Examples include: Inkas' village Machu Picchu in Chile (Fig. 5), Santorini in Greece, Sorrento in Italy.

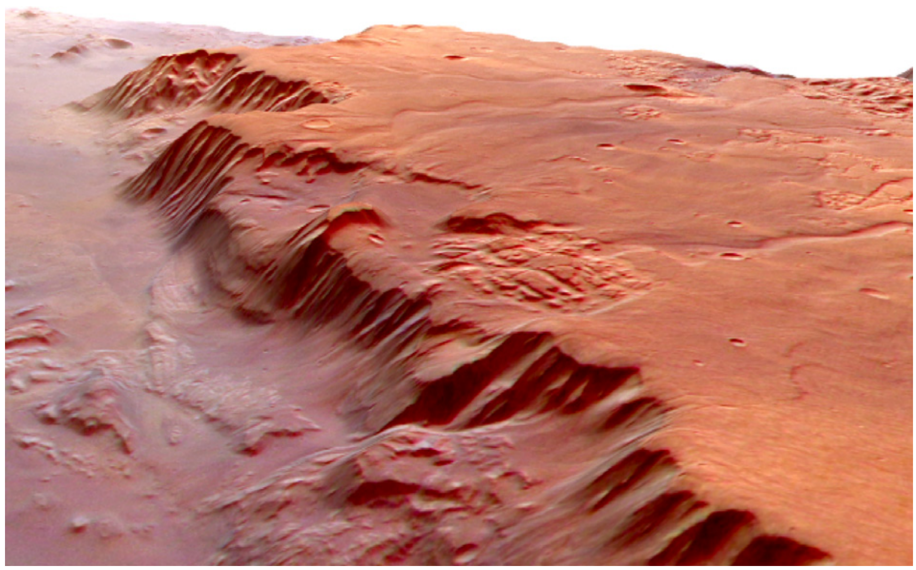

Fig. 4. Slopes in Eos Chasma (Photo: ESA/DLR/FU Berlin (G. Neukum)).

Fig. 5. Terrace town in Machu Picchu.

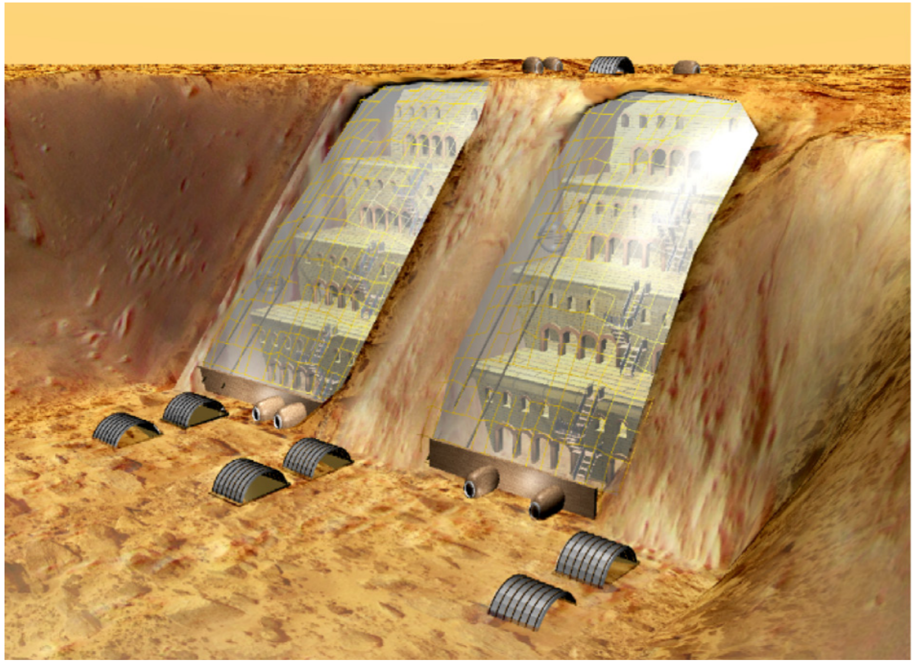

Fig. 6. Terrace Village concept.

Terrace Village concept (Fig. 6) proposes to use terraced architecture for Martian base. The slope is excavated to form terraces, then brick constructions are erected on each stair. Habitable chambers can be drilled under terraces. The communication between floors can be provided by light metal stairs and railway lifts. Airlocks leading outside the habitat would be mounted at the foot of the slope along metal wall and on the top as well. Magazines and garages are located under metal or inflatable vaults outside the habitat. The roof of the whole base can be sealed with transparent multilayer membrane of a high resistance, providing natural light for the base. In a case that each terrace has its own roof, a safety of the base is higher. To decrease the size of the roof construction and to allow its easy anchorage in the slope, terraces should be sculptured deep in the ground which is different than in terrestrial solutions.

3.3. Crater City

The surface of Mars is covered with plenty of impact craters. Their structure resembles patterns left by a rock thrown into fluid mud (Caplinger, 1994). Photographs from Martian orbiter Mars Express show their flat bottoms and steep but not jugged rims (Fig. 7). Smaller craters are usually bowl-shaped with slightly flat floors (Caplinger, 1994). The activity of water and living organisms on Earth caused many changes in surface shape of our planet – old terrestrial craters have been hidden and changed. However, it seems that some architectural solutions known and well developed on Earth can be successfully adapted for the Martian base design in a crater formation. Underground dwellings called *troglodytes* in Matmata, Tunisia are good examples confirming that in this case. A deep hole dug vertically into the ground functions as a courtyard of the set-

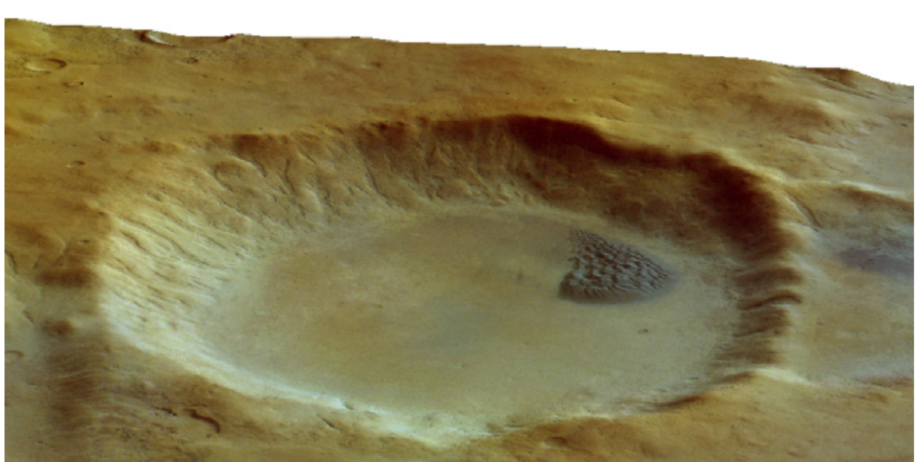

Fig. 7. Dunefield Crater (Photo: ESA/DLR/FU Berlin (G. Neukum)).

Fig. 8. A settlement in Matmata (Encyclopaedia of the Orient, 2007).

tlement. Rooms are excavated in slopes of the hole-rim (Fig. 8). Stairs cut in the ground lead to higher floors.

Crater City concept proposes to locate Martian base in the crater. Habitable space is provided by covering the natural hole with a tight cover (see Fig. 9). The amount of building material required to set up a base is minimized, that is a big advantage. However, dividing acquired space into functional quarters should be done with care. Habitable spaces can be located inside: tunnels drilled in the rims, tents anchored on the bottom or brick and concrete buildings. Underground lifts can lead to exits with airlocks on the surface around the crater. Stairs and light lifts inside the crater provide communication between internal floors. The central part of the crater can be used for location of agriculture, recreation, gardens and a water reservoir, while its periphery can be occupied by magazines, laboratories, etc.

3.4. Tubular Town

Valleys and hills form networks like, for instance, *fossae*. Sometimes they are very complicated like *chaos* (Fig. 10) or *labirynthus* areas. Those formations are unique and do not exist on Earth. Tubular Town concept (Fig. 11) proposes inflatable tubular modules, partly hidden under the ground. One part of the tube is fully transparent so it may function as agriculture and recreation space, while the second part is put inside a hole drilled in the hill. More

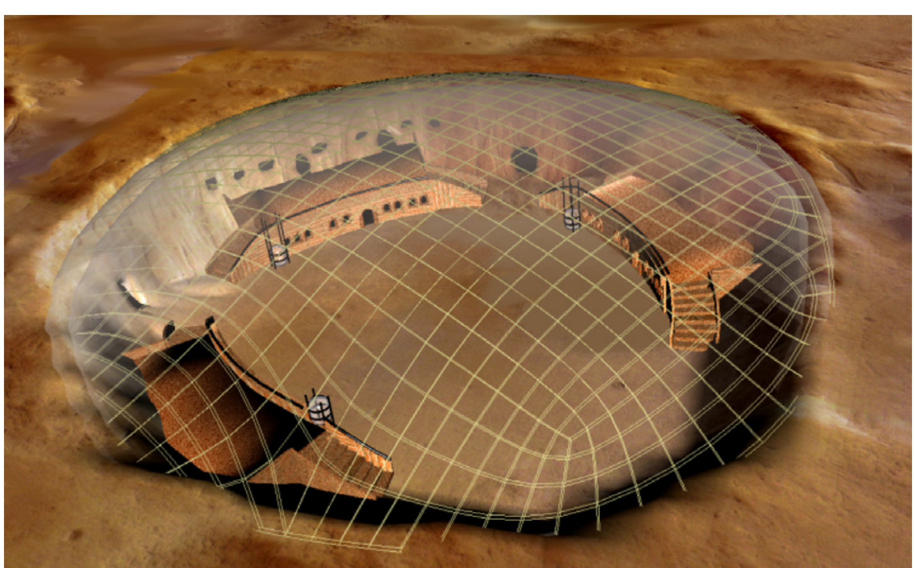

Fig. 9. Crater City concept.

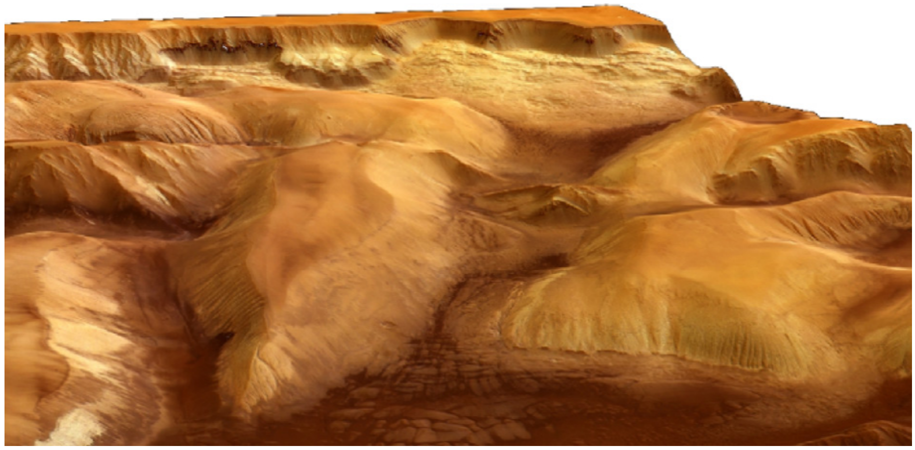

Fig. 10. A landscape near Ophir Chasma (Photo: ESA/DLR/FU Berlin (G. Neukum)).

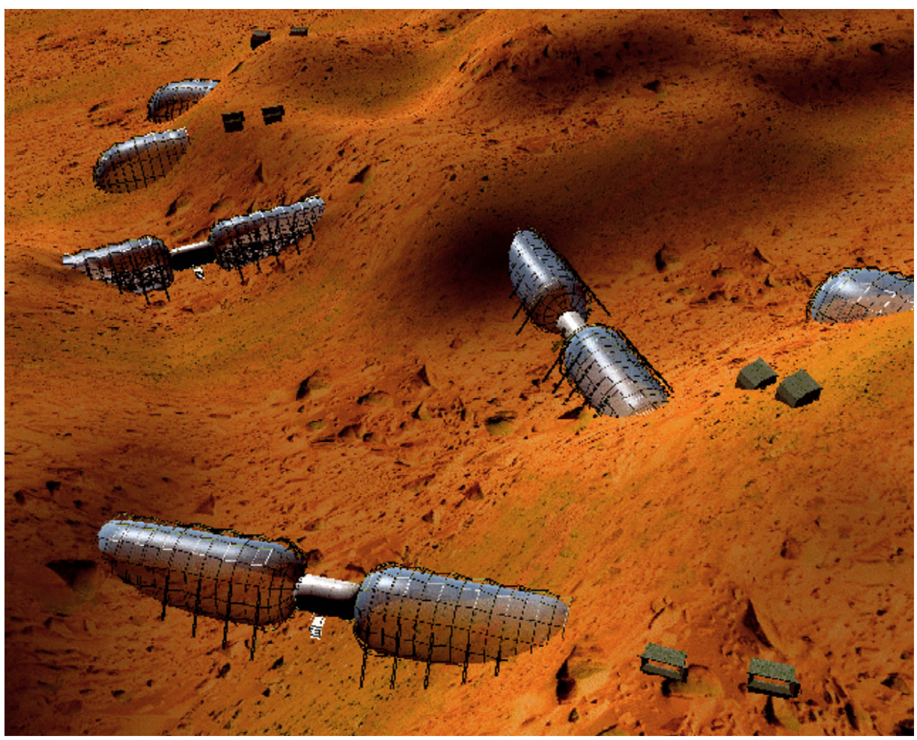

Fig. 11. Tubular Town concept.

secure area for flats and laboratories is recommended for this section. Extra periscope-like windows can be installed (Kokh, 2002b). Tubular habitats are connected by airlocks inside the hill, or on the surface. Layer of compacted ground put into inflatable cylinders helps to stabilize the construction and provides flat floor. Additionally, a net of strong ropes can anchor the construction to the surface. Chaotic terrain shape allows different combinations of connected modules to be designed. Some tunnels can be drilled through narrow hills. In this case two ending skylights are obtained. Easy access to the working place is achieved for the drilling machine as it moves only along valleys bottoms. Inside the tunnels people are sheltered against radiation.

4. Conclusions

Different possibilities to lower costs of building Martian base have been proposed so far. In this paper, several new are pointed out. Employ the shape of terrain is the first advantage. Hills can function as walls or some habitable volume is specially excavated inside the hills. Use different but the most exact materials for each construction element is the other opportunity. When one building technology is chosen for the whole structure, it seems to be the easiest way to achieve the low-cost architecture. However lightweight membranes brought from Earth are the best solution for windows or transparent covers and walls, and bricks made on site from local sources are the most proper for internal sections as the easiest in erecting and sustenance for people. One another recommendation is proposed too. When habitable spaces are very close one to another, the usage of available volume is maximized, thus not wasted for long communication routes. In the paper four concepts are presented: Tunnel Outpost, Terrace Village, Crater City and Tubular Town. Each of them in a different way deals with recommendations for the low-cost base, for example: Crater City has the most concentrated volume, in Tunnel Outpost almost the whole habitable space is drilled in the steep slope and building materials are needed exclusively for windows and agriculture modules.

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