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URBAN PLANNING IN SPACE ON THE EXAMPLE OF IDEACITY PROJECT

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ABSTRACT

Life on Mars seems to be getting closer to us. We are currently not asking whether it will ever be possible, but rather determining the real date. We need to design the entire infrastructure, resistant to previously unknown problems such as radiation, strong sandstorms or low temperatures. Fortunately, the longer we study the red planet, the more opportunities it gives us. If we make good use of its resources, the planet can offer us a completely new life with new views.

The presentation will discuss urban concept and space architecture on the example of the "Ideacity" solution, a colony project for 1,000 people implemented for the Mars Colony Prize competition. The entire design process will be presented, based on the analysis, research and consideration the team faced. Starting from the selection of the location of the base location, through the analysis of undefined and difficult conditions on Mars, to design.

KEYWORD

Mars base, city planning, colonization of Mars

INTRODUCTION

Manned space missions began in the 1960s of the 20th century(1). Currently, space exploration and colonization are the driving force behind conducting scientific research in many fields of science and engineering. Thanks to this, we get better and better solutions that enable us to achieve the great goal of learning and the colonization of space by people.
To the present time people have landed on the Moon only, the natural satellite of Earth. The first manned missions to Mars are planned for the years 2025-2030 (Plans of World Space Agencies, connected with human exploration of the Moon and Mars). 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.

However, we know that this task will not be easy. Initially, we only assume the creation of a Mars base but when we succeed the next step will be the city. Thinking about planning cities on Mars, we will have to deal with many problems that do not occur on Earth. Another difficulty is the fact that we haven't explored the entire planet yet, so we can't prepare for all eventualities. In addition, when planning Martian cities, we should take into account all the mistakes we have made on Earth. In this way we have the chance to create a better alternative space. The aim of present paper is show our design path. You will see all aspects. That means the Mars condition ways of creating a space base examples of space base and Ideacity concept.

Ideacity is a project of self-sufficient city for 1 000 people. We won 5th place in The Mars Colony Prize in Los Angeles, 2019. Our concept takes into account not only urban planning, architecture and design but also economics, social issues and law. Thanks to this we were able to design a self-sufficient place to live.

MARS CONDITIONS

The first design stage was to translate available knowledge about Mars. This allowed us to identify the most important threats that we had to take into account in the design process and choose the best location for our settlement.

Unknown area

We're still exploring Mars and finding out new things.

Soil

The surface of Mars is covered with a thick layer of crushed rock, dust, soil and other related materials. This is the effect of strong weathering caused by large daily temperature fluctuations and winds. I call this land very fine, reddish dust. It settles in hollows and creates dunes pushed by winds. Those parts of the planet that are not covered are usually dark, almost black. Mineral composition of Martioan rocks: SiO_2 - 44%, Fe_2O_3 - 17%, MgO, - 9%, Al_2O_3 - 10%, CaO – 5,5%, SO_3 – 5,5%, Na_2O – 5,5%, TiO_2 – 5,5%, K_2O – 5,5%, MnO – 5,5%.

Element composition of Martian rocks: 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% (2).

Radiation

A much larger amount of each type of radiation can reach the surface of Mars than it does on Earth. This is due to the low density of the atmosphere. There are two main sources of radiation harmful to human radiation: the sun (the most dangerous aspect) and space rays (2).

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 (3).

Pressure and components of the atmosphere

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. 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 and it is less than 1/100 of the Earth's pressure. Martian atmosphere mainly consist of carbon dioxide, and there is a low oxygen concentration. The composition of Martian atmosphere: 95.72% CO2, 2.7% N2, 1.6% Ar, 0.2% O2 (4).

Temperature

Yearly fluctuations near the surface of the planet are large: during the coldest winter nigh the temperature can drop to minus 140 °C, and during the warmest summer day the temperature can rise to plus 27 °C. The average Martian temperature is only minus 60 °C (3).

Winds and sandstorms

The Martian atmosphere is very thin. Nevertheless, there are winds on the Red Planet, sometimes reaching enormous speed and strong enough to sweep the dust off the surface very high. The key reason for the creation of winds on Mars is the sublimation and condensation of carbon dioxide (the main element of the atmosphere), which follow temperature changes. The creation of winds depends on the shape of the surface. Very strong winds can travel huge distances practically unstoppable, and the beginning of sandstorms cover even the entire planet. Therefore, sandstorms last for several or several months (5).

Water

There is no liquid water on Mars. Under the conditions of pressure and temperature there, water in poles 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 (6).

Land relief

There are various formations on Mars, some similar to those known on Earth. Terrain on Mars is as diverse as on Earth. There are no water barriers, seas and river streams. The Martian landscape is shaped for millions of years to become as it is now. The main factors of this process are: wind and water, volcanic eruptions and meteor falls. Land formations on Mars can be divided into several main groups: volcanoes, plains, valleys, slopes and craters (3).

- VOLCANOES - there are three types of volcanoes on Mars: mons, tholus and patera (7).
- 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 (3).
- 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. The next are chasmata and fossae. Chasma is a very deep and extended valley with steep slopes, similar to the Earth's canyon. Fossa is an extended and rather shallow valley (3).

- 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 and scopulus—an escarpment with irregular line of the ridge of the slope. 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 (3).
- CRATERES - 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 (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 (Figure 1)(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.

Figure 1 The first Martian habitat according to the DRM program (NASA)

THE LAND FORMATION INFLUENCE ON THE ARCHITECTURE OF MARS BASE

Architecture can relate to terrain in various ways. Sometimes it actually dominates the appearance of the base, sometimes it has no effect on it. In the picture 1 A) Architecture is dependent on typography which imposes specific forms but does not interfere directly in the area. The terrain serves us to solve a specific problem. This gives us protection against the wind and thus significant temperature changes. In addition, significant land modification and use significantly reduces construction costs. In example B) we have a very similar situation except that we interfere with the existing landscape and modify it. The investment costs are higher but also the habitat area increases which affects the comfort and ergonomics of use. C) the base is independent of the surrounding landscape. You do not have to limit yourself to the location of the base. You can use different technologies. This type of habitat is the most expensive to make and requires a lot of work (8).

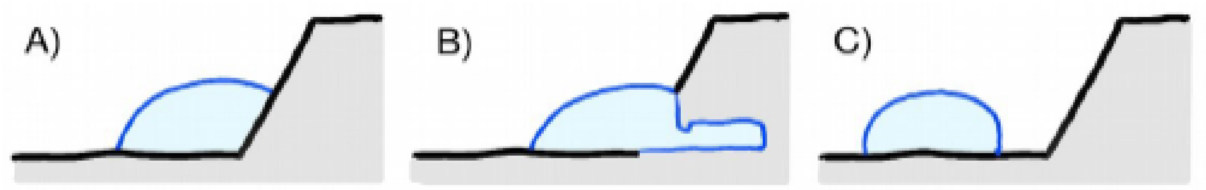


Figure 2 Different cases of architecture referring to landscape: A) a base located within an existing landscape, B) one put within a transformed landscape, C) one independent of a landscape (Kozicka).

Below are the conceptual sketches developed by dr Joanna Kozicka presenting various base solutions relating to the terrain (8).

Base on a flat land

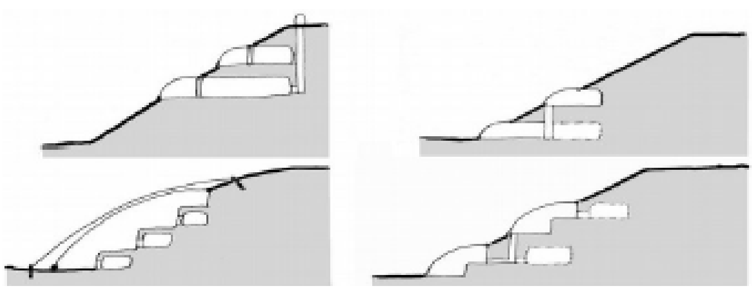


Figure 3 Study concepts of multi-storey base located within a slope, an entrance atop or at the foothill (Kozicka).

Base inside a hill

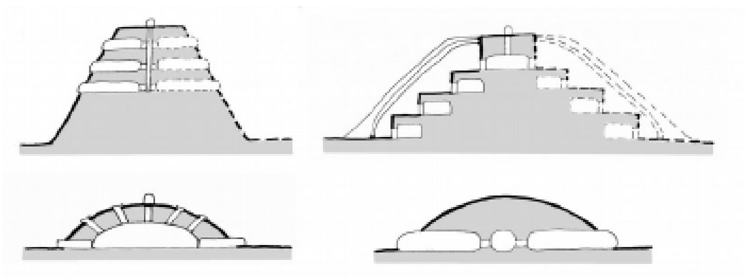


Figure 4 Outline concepts of multi-storey base located in a hill (Kozicka).

Base in the valley or crater

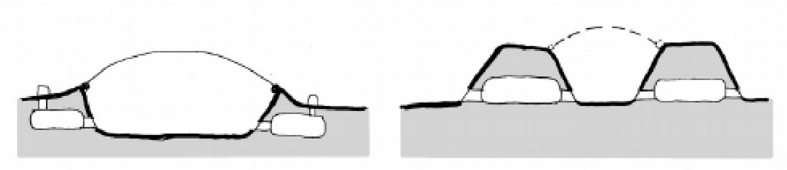


Figure 5 Outline concepts of bases located in a crater and in a valley (Kozicka).

Base in chaotic terrain

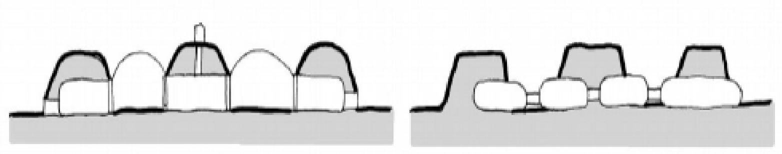


Figure 6 Outline concepts of bases located in a chaotic terrain (Kozicka).

FORM OF BASE

As mentioned earlier, the form of the base may depend on the terrain and on flat terrain it can take any shape. It can be made on the surface or hollowed out below the ground surface. The external form is dictated by the pressure difference between the dense atmosphere inside the habitat and the rare one outside. The gases inside will exert considerable pressure on the walls of the building. Therefore, optimal pressure distribution can be ensured by rounded forms. Basic streamlined forms: sphere, cylinder, torus, dome, arch, vault and cut of torus. Other shapes will be unevenly stressed, which will lead to rapid structural fatigue and cracks.
The base form can take the following forms: adjacent form, a complex of buildings under one cover or a multi-module complex.

FUNCTION OF BASE

There could be extinguished three main factors influencing functional solutions for Mars 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.

CONSTRUCTION OF BASE

The construction's solution defines: how the base will be localized on Mars, what building units will create it, what forms and sizes of buildings are acceptable, system of connections between building units, shape of insides, space of insides, number of floors and their construction's forms and solutions, places of exits to the surface, possibility of lighting with the daylight.

We can solve in many different ways: fixed construction from metal and plastic, regolith construction, ice construction, drilled construction, expanable construction, isolation materials and installations

COMMUNICATIONS

When designing a Martian habitat, communication between objects is a very important aspect. You need to design it in a completely safe way but also allowing comfortable movement between objects. Different kinds of exits to surface form hermetic Mars base: on surface (typical airlock) or underground (communication route inside habitable space or independent).

CITY PLANNING

Designing the city on Mars will be solved in many layers. In addition to factors related to conditions on Mars, we must remember the social context. We must take into account the basic functions that are necessary in every terrestrial city: housing, services, industry, trade, transport). Then we have to relate them to Martian conditions, because not everything will function in the same way here.

To properly design a city, we must separate functions and spaces. Urban Space: public urban space (roads and public facilities, streets, parks, squares), semi-public urban space (all spatial forms used in public, which are administratively controlled, eg town hall, schools, stations), public space, the use of which is institutionally controlled and which is used by specific social groups (eg meeting areas, churches, sports and recreation centers, cultural centers, public services), private family space, controlled only by the family, eg a single-family house, flat and individual private space, e.g. own room. Next step is urban transport can take place on foot or using appropriate means: individual transport (eg bicycle - including city bike; moped, motorcycle, "Segway" type vehicle), group transport (eg Personal Rapid Transit, rickshaw, passenger car, taxi , collective taxi), public transport (e.g. buses and trolley buses of various designs and sizes - including Bus rapid transit; trams - including fast tram and metro; city rail - including cable car, funicular, metro; water transport, including ferry , hydrofoil, water tram) (9).

„The city is an essentially shaped type of housing estate, determined by the existence of a specific partial community, concentrated on a certain area, with a separate organization, legally recognized and producing as part of its activity a set of durable material devices with a specific: physiognomy that reflects a separate type landscape." (10).

EXAMPLES OF SPACE BASE CONCEPT

Although no base has been physically created in space, many concepts have been created over the years. Below are some of them.

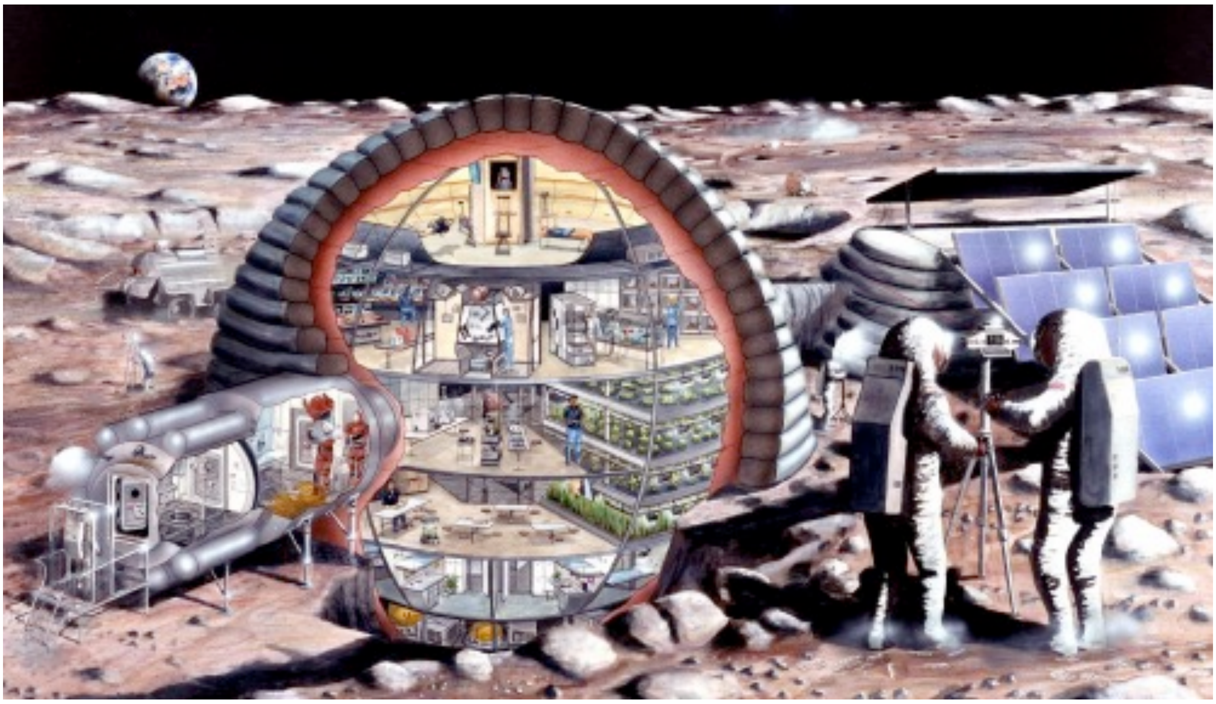


Figure 7 The concept of the Moon Base by Kennedy and Cerimele (JSC NASA)

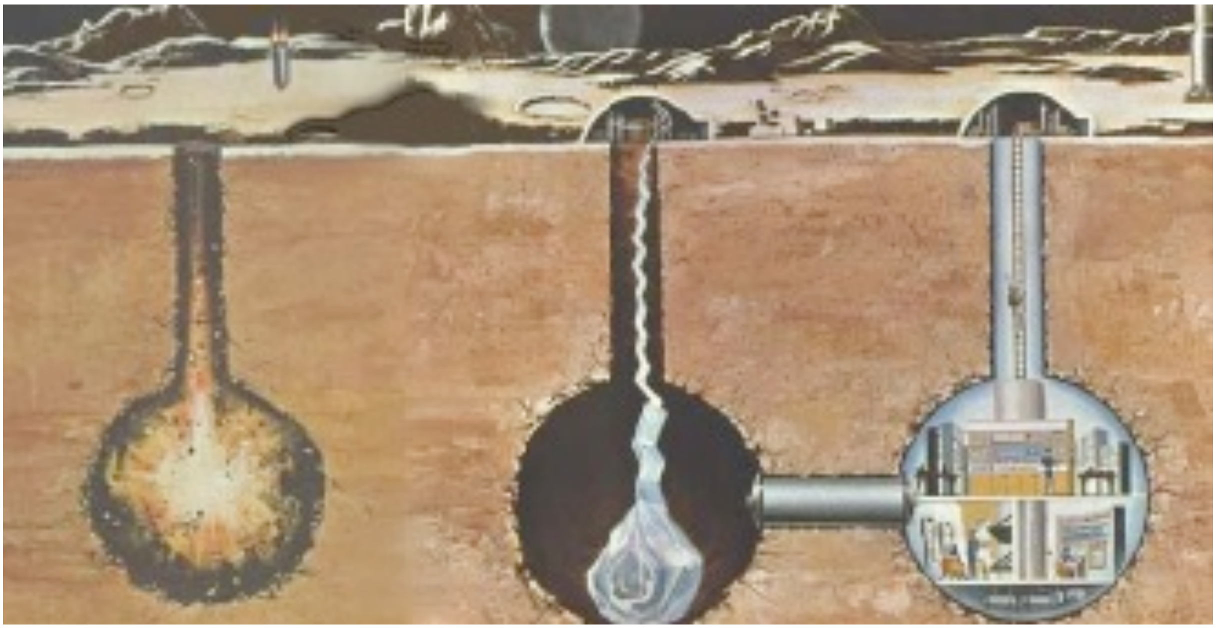


Figure 8 A concept of the underground habitat presented by Cole i Scarfo(1965)

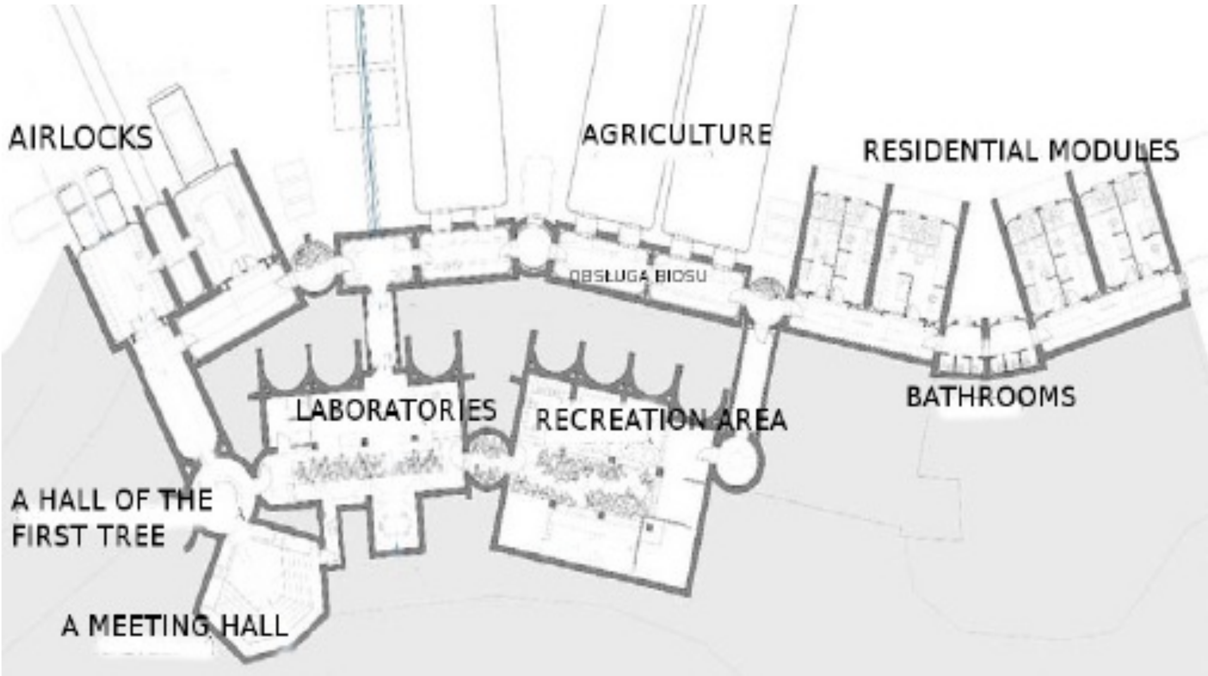


Figure 9 A horizontal projection of the habitat (Petrov 2004)

DESIGN CONCEPT OF IDEACITY BY INNSPACE TEAM

Location

Ideacity was designed on flat terrain, as a place of destiny for the Mars base, we chose Arcadia Planitia (figure 10). But its location could also be in another location because its location is not dependent on the terrain. From the current information the location we have

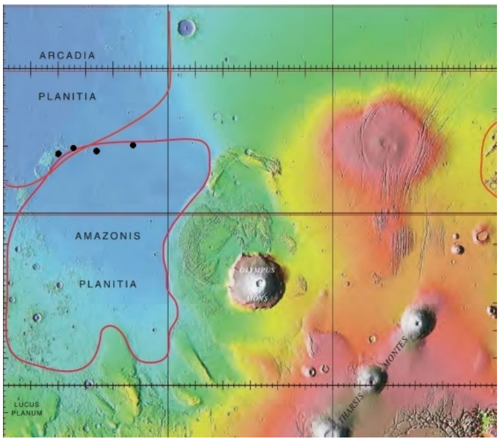


Figure 10 Arcadia Planitia (NASA)

chosen is the most optimal in terms of ease of landing and access to water. The terrain is flat there are no stones here which will allow us to drill more easily.

Idea

The idea of our city is the Renaissance concept of the "ideal city". The "ideal" nature of such a city may include the moral, spiritual and legal characteristics of citizenship, as well as the ways in which they are implemented through urban structures, including buildings, street layout, etc. The land plans of ideal cities are often based on grids (mimicking Roman planning spatial) or other geometric patterns. Thanks to this it is also geometrically perfect. In the Renaissance the Leonardo da Vinci project was also interested in this issue. Leonardo wanted to design a city that would be more coherent. Effective communication, services and sanitation were important to him. His ideal city integrated a number of connected channels that would be used for commercial purposes but also as a sewage system (11).

An example of such a city is Palmanoca (figure 11).The cities of Palmanova and Nicosia, whose Venetian Fortesses were built in the 1590s by the Venetian Republic, are considered to be practical examples of the concept of the ideal city. Another notable example of the concept is Zamość in eastern Poland, founded in the late 16th century and modelled by the Italian architect Bernardo Morando (11).

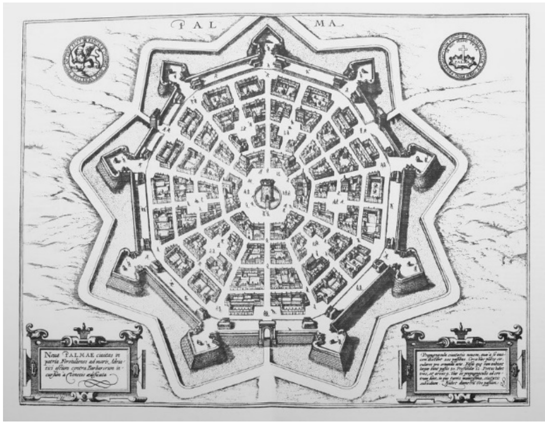


Figure 11 Map of Palmanova in 1593. The town is encircled by massive Venetian Defensive Systems that are a UNESCO World Heritage Site.

Development

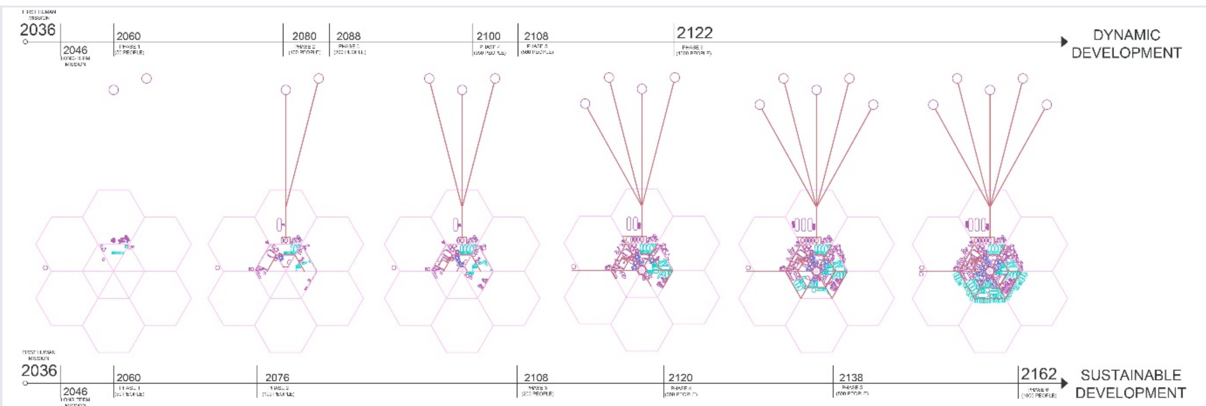


Figure 12 Evolution of Ideacity

The determinant of city design was to determine the evolution from the first settlers to the final version of the settlement. Thanks to this we were able to determine the most important functions, appropriate distribution and arrangement of the remaining space. This simulation also helped us in economic calculations because such a project requires a far-reaching plan. Based on the calculations, we assumed two possibilities for the base to grow over the years. Thanks to this, we will be prepared for unforeseen circumstances. At the beginning of the design process, we also conducted a risk analysis.
We should build the settlement from the very beginning according to the final plan, not randomly. Thanks to this, project implementation will be cheaper, faster and easier to perform in the long run. (figure 12) The figure shows only selected stages of mars colony development. We assume that the first base will consist mainly of ready habitats coming from Earth. In the next steps, we need to adapt most ground-based solutions (related to for example, agriculture, fuel production or resource processing) to Martian conditions and provide them with access to water, food and air. Finding raw materials and developing a way to extract them will be an important stone.

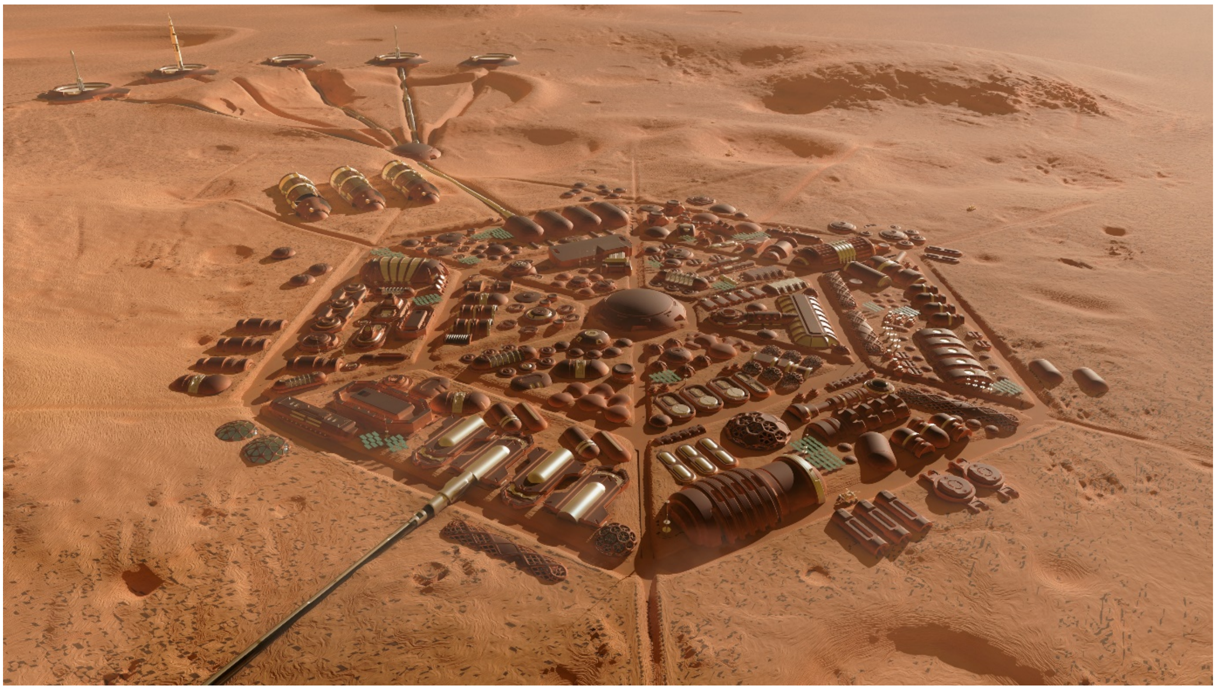


Figure 13 Visualisation of Ideacity

Architecture

After conducting all the analyses the final appearance of the city is shown by visualization (figure 13) and plan (figure 14). We took into account values and visual experience. Main features are ideal city concept, a reference to renaissance, hexagon grid, high automation, security and self-sufficiency. The city that we propose is built on a grid of hexagons. In the city center is the main point of the city to which all other functions lead. The structure of the urban space consists of individual building complexes of various functions and forms, public space systems, communication systems, complexes and complexes of green areas, as well as infrastructure systems. That is why our city is a very complex organism whose spatial structure consists of ground and underground elements. Separated city communication is aimed at radiation protection. Underground communication is dedicated to people, so they can move around the entire base without suits. The network of underground corridors allows access to each building and thanks to a special marking system, navigating the settlement is not difficult. The walls of the corridors grow vegetation that produces oxygen but also increases aesthetics and improves mental aspects. Roads on the surface are laid out on the contour of the hexagon and radiate to its interior. They are hardened and have been designed for vehicles. Their width of 5m allows two rovers to pass by freely. In other places, transport takes place on a normal surface, using rovers, and reaching each building is possible by maintaining minimum distances (at least 3 m) between them. Also, the distances between the designed structures and solar panels are suitable for the rover (minimum 2.5 m) to allow maintenance. We have also designed parking lots for rovers. The transport of resources, e.g. between rocket landings and distribution warehouses, and between the base and the mines takes place by rail. Some resources, such as water or air, are transported by pipeline. Main features of transport are optimization of transport, main roads on a hexagon plans, short distances, less than 400 meters to the most important places, separation of road for pedestrians and rover, safety pedestrian traffic - underground, access to every building, cargo rail and parking lots. The exact communication was presented in the communication analysis (figure 15).

In the settlement we have included all the most important functions for the proper functioning of the city (figure 16). We have here residential complexes, entertainment, industry, crops, education, prayer houses, parks, medicine with research centers, a water and air treatment plant and even a hotel. In the middle of the assumption is a center that refers to the "market" in European urban assumptions. It is a place where the main social and entertainment life of the mars base goes on. According to the principles of new urban planning, the most important functions for each resident are located at a distance of about 0.25 miles (0.40 km). This is the distance that makes us prefer to go on foot than reach for the car (12). Thanks to this procedure, residents will have a minimal dose of movement every day, which is strongly recommended for the proper functioning of the human body, especially in space conditions.

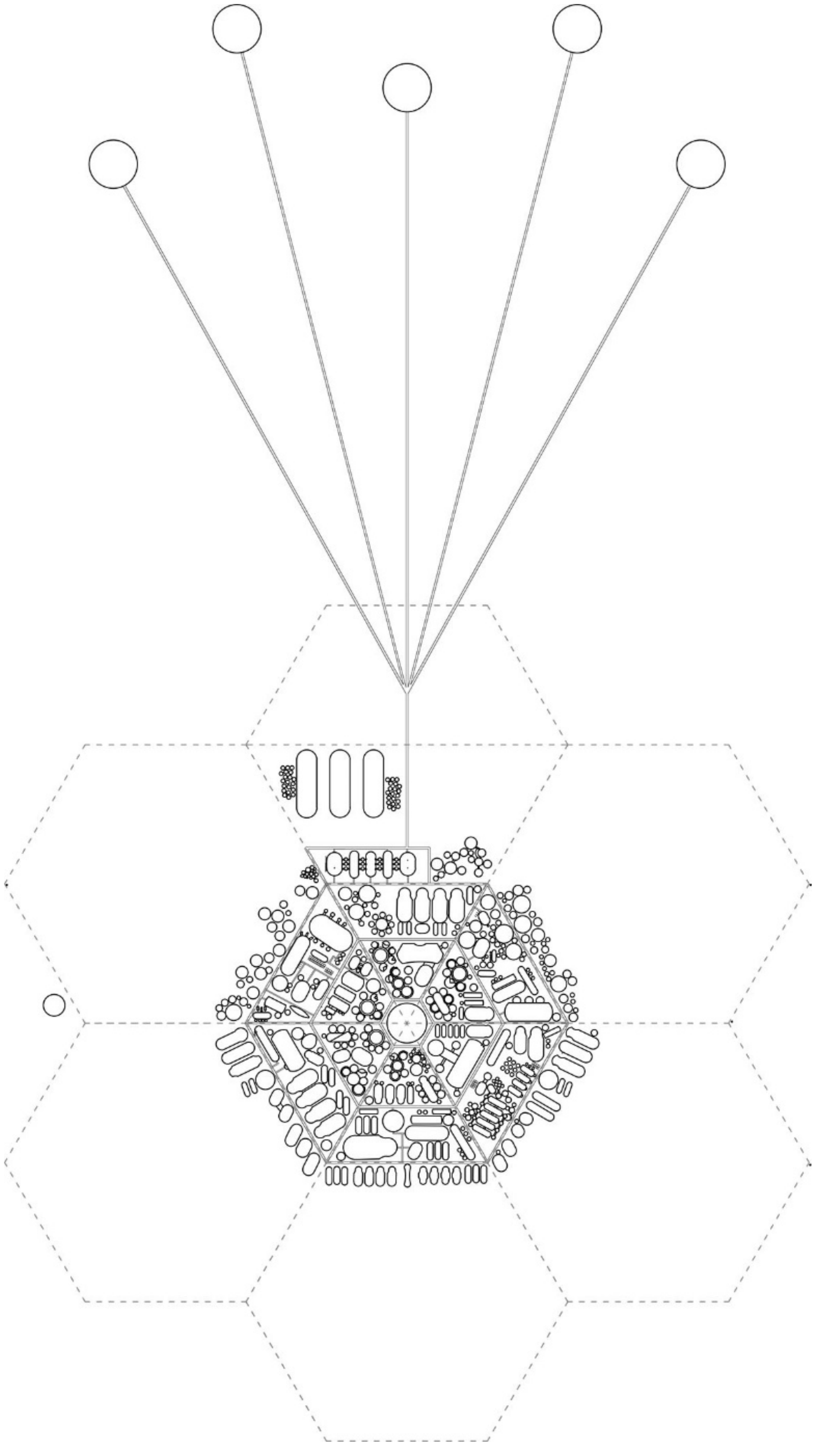


Figure 14 Plan of Ideacity

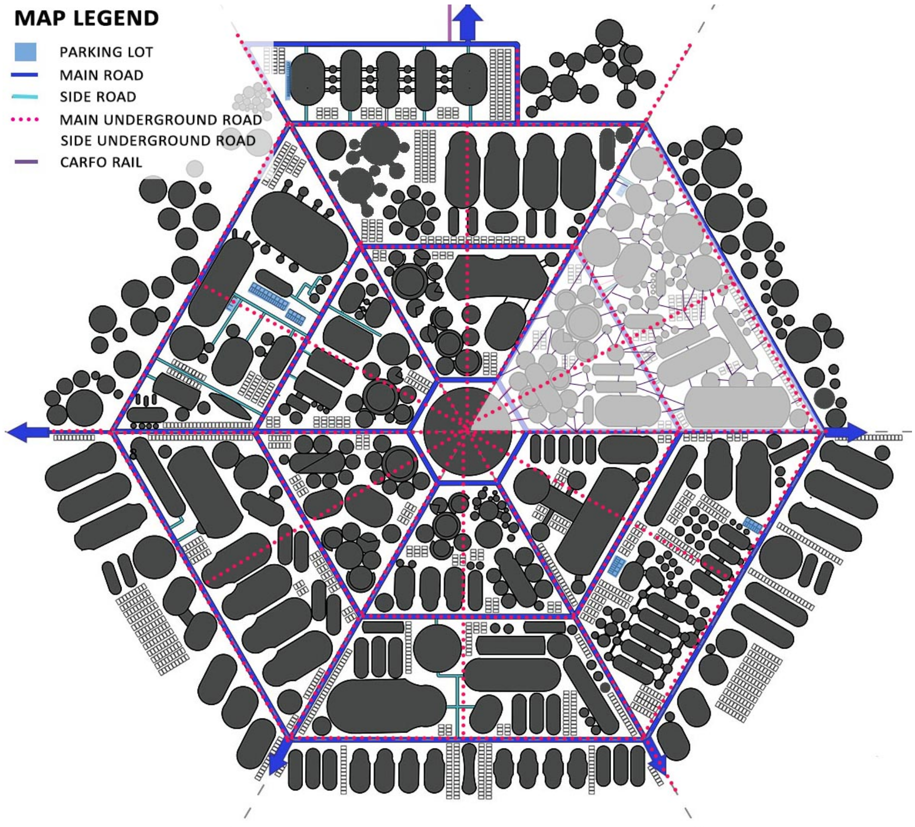


Figure 15 Transport analysis of Ideacity

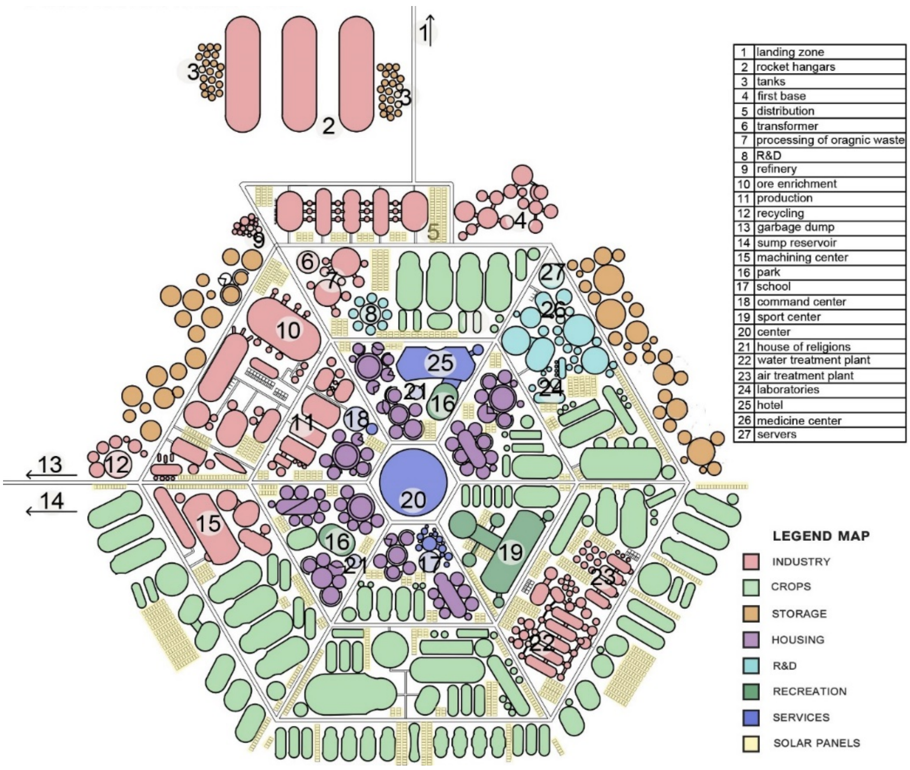
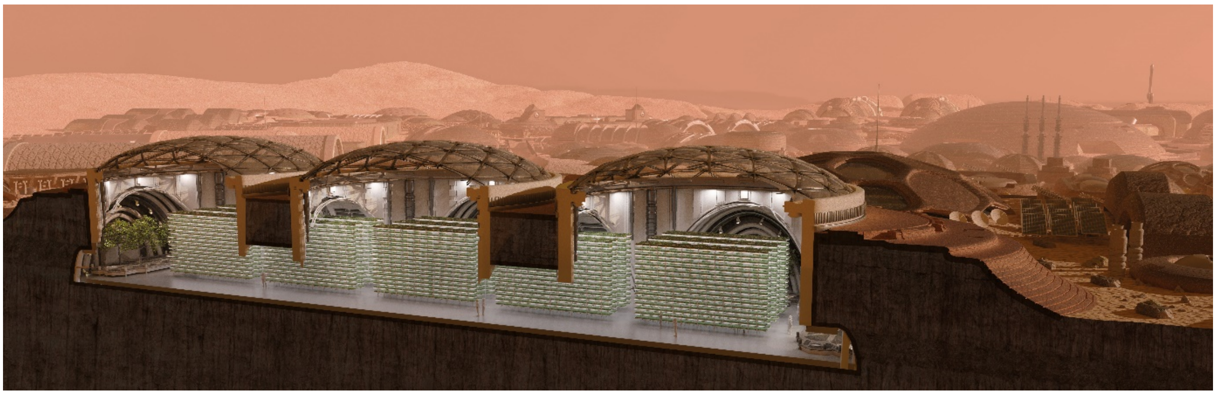


Figure 16 Functional analysis of Ideacity



Picture 17 Architecture section of crops

The key part of our settlement is the use of natural protection which is regolithic radiation. We are aware of the difficulties this solution will bring but our risk analysis showed that it would be the most optimal solution for us. Ensuring the safety of residents was a key aspect for us. The buildings have two (for industry) to four floors for crops (figure 17). The lower floors provide maximum security. Buildings are built on a circular plan, ellipses or similar shapes, as these are the best forms in terms of pressure distribution. In addition, the roof surface is rounded to reduce sand build up and thus avoid additional loading conditions. The constructions are made by 3D regolith printing using printers placed on rovers, machines or robot arms. We decided that Martian land is the best raw material for building the base. We have it in abundance, which will significantly reduce construction costs. Some roofs (mainly above the common areas) are made of transparent material – ETFE (13), which provides natural light for habitats, improving people's quality of life and allowing planting and growing vegetables in unusual spaces. We conducted a strength analysis to make sure our structure could withstand.

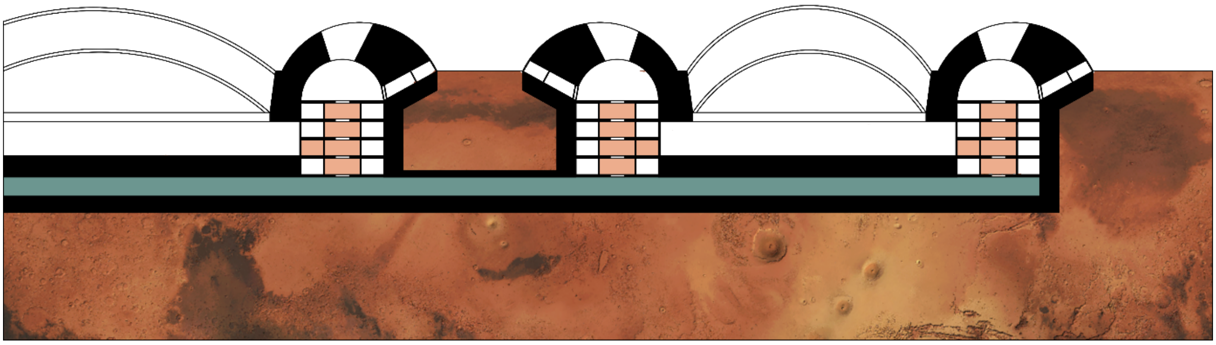
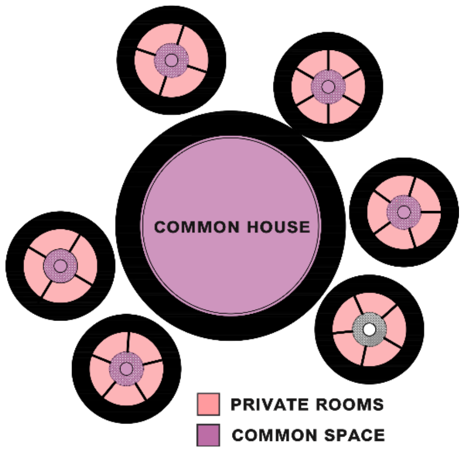


Figure 18 Architecture section of residential buildings

When designing apartments, we focused heavily on social issues. We appealed to the idea of cohousing. Cohousing is a purposely designed space where people get to know each other and take care of each other. People have their place but you are also divided by significant spaces both inside and outside. We have designed a residential complex. About 100 people live in each complex. This can be seen perfectly on the architectural cross-section (figure 18). In the middle is a shared house, on the sides there are rooms with a private or shared bathroom. Zoning is shown in figure 19. The Commonhouse is where social interactions and community life begin. Inside the shared house there is a large dining room and kitchen. This allows you to cook and prepare meals in groups together. Psychology has shown that people who interact with other people feel better. In addition, people have the opportunity to get to know each other in a natural way, which later translates into other aspects of the life of the settlement. When designing these facilities, access to natural light was extremely important to us. We also included natural plants that provide oxygen and have a calming effect. The common area also has an entertainment area and a gym.

The private part consists of single rooms. They are modularly designed (figure 20). This will allow combining modules to create a larger room for a couple or several people. The room dimensions are optimally suited to the needs of the inhabitant. Residents have their own space with a bed, desk, chair, wardrobe, computer and music player. Residents will choose their room decor individually.



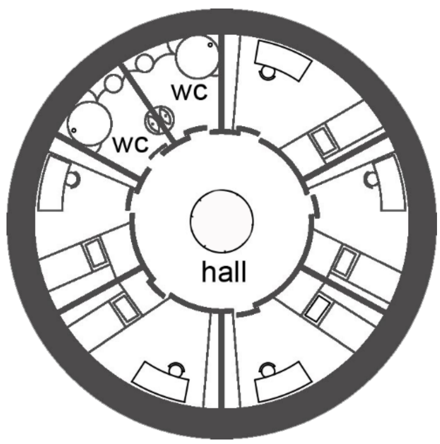


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Figure 19 Functional plan of living zon

Figure 20 Typical floor plan of living zone

Design

When designing our habitat we used bionic and parametric architecture. We tried to maximize the relationship between digital tools and architectural design. Computational design includes both advanced techniques for manufacturing custom geometries as well as new dynamic and adaptive spatial operation modes. The structure system is demonstrated by working with models in mathematics, biomimicry, human physiology and psychology. The synthesis of these domains and computational tools to obtain performative habitat formations is what drives our design process.

In the park we decided to print a flower garden. 3D printed counterparts would be aromatic like flowers and plants known to us from Earth. They could also "grow" because each plant would consist of smaller elements that could be changed or added over time as if they were growing in nature. We have also included natural plants in every possible place. They not only provide oxygen but also have a calming effect on people. We place them in corridors, common spaces, showrooms, and even selected some buildings for parks. Secondly, we used color psychology to make the interior more friendly for everyday life. Third, ergonomics, i.e. the process of designing and arranging jobs, products and systems. Refers to people's work - work spaces, sports and leisure, health and safety. Uses anthropometry, biomechanics, environmental physics, body systems, applied psychology, and social psychology. When designing, we took into account natural light which is extremely important. In all places, we took care of different environmental conditions, such as the intensity and color of artificial light. Other factors were less important to our respondents but we included them in our project. We designed various spaces to avoid the impression of monotony and created designer interior furniture (3D printing gives us unlimited possibilities in this regard). Caring for a balance between responsible management of raw materials and unlimited space on Mars, we have provided much more living space than a minimum for the well-being of residents. It was important for us to use different textures (e.g. materials such as cotton, linen, silk) in the decor to give the impression of coziness. We decided to take advantage of the possibilities offered by the new technology and display views in the place of some walls.

Evaluation

1000 inhabitants in the settlement is a good time to become self-sufficient as a Martian base. It will probably be just the beginning, because if we manage to create a safe place to live on another planet then we should develop it. With the infrastructure we have designed, it will not be a problem to expand the settlement to include more inhabitants (figure 21). Some systems in our base (like the refinery or the entire industry) are designed for 1,000 people but they can be easily adapted to a larger number of inhabitants. Design Ideacity we had in mind the further expansion of the base. We adapted our project for easy further development. This will happen radially by adding flats and greenhouses. However, we believe that we should look for a different place on the surface of Mars for the second spot base and each subsequent one to fully colonize this planet. In this case, we should also start terraforming Mars. In this way, she would become more friendly to people. We should be careful not to destroy Mars like Earth, so we should develop our settlement in a sustainable way.

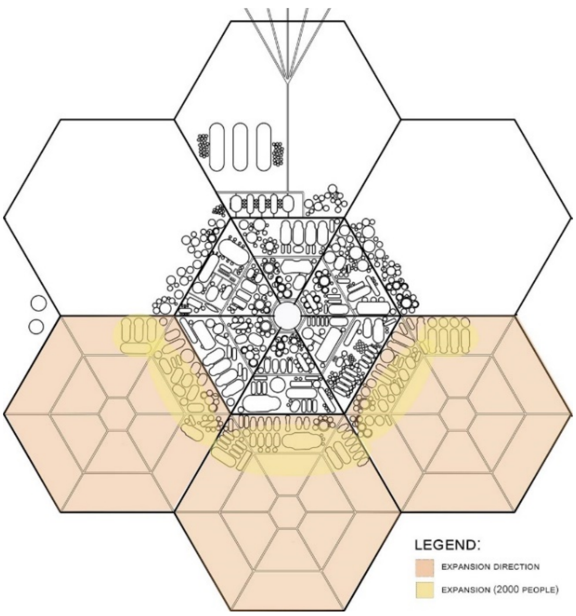

Figure 21 Evaluation of the Ideacity

SUMMARY

We believe that in the near future we will be able to colonize Mars. To get closer to the goal we should conduct research today and think about possible problems and potential solutions. We should strive to make Mars a better place to live than Earth. Therefore, we should develop the settlement sustainably. It will be very important for the Mars base to produce all the necessary materials and be self-sufficient. Thanks to this, she will not be dependent on Earth and will be able to develop more dynamically. Considering all the above arguments and considerations we designed Ideacity as a self-sufficient settlement. We also emphasized that in addition to technical problems, the social aspect will be extremely important. We tried to find a solution for all aspects of people's functioning as a society on Mars.

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