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Functional Organization of extraterrestrial underground base on Mars

Valentyna Praslova, Yuliia Riabets, Viktoriia Shchurova, Olena Zinovieva, Maryna Harbar

***Abstract:** In the article relevant problems of colonization of other planets by mankind and development of extraterrestrial settlements are examined, in particular colonization of Mars and creation of Martian multifunctional base. Modern projects of leading space agencies for research and Mars colonization, shipping of equipment and the first settlers to the planet, and also projects of the first Martian habitats within the modern space technologies are discussed. In response to that natural and climatic conditions of the planet Mars which could substantially influence the formation and development of extraterrestrial multifunctional base are analyzed. Main natural and climatic factors such as high radiation background, absence of atmosphere, extreme temperature profile, low gravity, that have significant influence on formation of the Martian settlement on functional architectural and organizational levels are determined in the study. Functional model for establishment of an autonomic multifunctional base in extraterrestrial environment under the surface of the planet is proposed like the most fully satisfying the requirements for organization of extraterrestrial artificial environment for human's long-term stay considering extreme climate conditions of planet Mars and the desire to create comfortable conditions for livelihood of Martian pioneers. Basic blocks are determined and zones being parts of these blocks, which form the basis of the functional organization of extraterrestrial multifunctional complexes are detected. Possible options for functional connections between blocks and zones are analyzed.*

***Keywords**: architecture, functional organization, extraterrestrial complexes, underground multifunctional complexes, colonization of Mars.*

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* Correspondence Author

Valentyna Praslova PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Email: praslova.vo@knuba.edu.ua

Yuliya Ryabets PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Email: riabets.ius@knuba.edu.ua

Viktoriia Shchurova PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Email: shchurova.va@knuba.edu.ua

Olena Zinovieva PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Email: zinovieva.os@knuba.edu.ua

Maryna Harbar PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Email: garbar.mv@knuba.edu.ua

I. INTRODUCTION

Term "The Mars race" [3], [4], [5] means competition between various national space agencies and private companies in the field of crewed missions to Mars. It involves also landing on Martian surface and building a crewed base there. Some projects suggest colonization of Mars, others have scientific nature. Notably, the radiation protection during the flight is still an unsolved issue. In case of its solution space flight is real [the flight to Mars]. NASA's contractor "Boeing" corporation prepares Space Launch System project, that has the goal of a crewed Mars mission. Within the project entitled Hundred-Year Starship NASA's scientific lab Ames Research Center work on a one-way trip to Mars with the goal of its colonization. The return flight would be possible only when the colony could organize production of a sufficient number of necessary elements and materials from local resources in the field on their own. Within this project NASA plans a crewed mission in the 2030s. NASA's competitor is the China National Space Administration (CNSA). China plans a launch of a robotic mission on Mars in 2020s, and afterwards a crewed mission is expected [6]. In chinese deserts two bases for cosmonaut trainings and launch to Mars have been built. The first base «Mars Base 1» is in the Gobi desert. It is Martian base simulator, which was created by Center of Astronauts and China Intercontinental Communication Center within the space program for specialists training for Mars mission. The base consists of central dome and nine additional modules, where technical rooms, living quarters, a greenhouse and an airlock are located. The object operates as an educational institution for astronauts and researchers and is open to the public and guided tours. The second base AMADEE-18 Mars is located in Dhofar desert in Oman. This base is for colonization equipment testing [7]. United Arab Emirates with Mars Science City project are part of the UAE Mars 2117 Strategy, under which the first Mars settlement should be build during next 100 years [8]. Non-profit organizations also play an active role in Mars development and colonization. The organization Mars society is dedicated to Mars colonization and awareness-raising campaign on the benefits of its research as well as exploring opportunities for privately financed mission to the planet. The aim of the society is to show that Mars is an achievable goal through implementation of several practical, technical and other projects. The organization Inspiration Mars Foundation proposed to launch a crewed mission to flyby Mars [1].

In 2002 Mars Desert Research Station project was started, according to which Martian expedition was modelled on the base, located in Utah. Changing crews work for 2 weeks conducting medical, geological and astronomical research. Different researches were conducted to study possible issues during the flight to Mars and stay on the planet: analogue stations were built, experiments modelling crewed mission to Mars were conducted [9]. Mission ExoMars also tries to find out whether life is possible on the red planet, launching a stationary lander called Schiaparelli to the surface of a neighboring planet. The Trace Gas Orbiter, which shoots and scans the planet surface, also was launched to the orbit. ExoMars's 2020 goal will be to search microbiotic life on Mars. Specific drill and instruments for the search of organic materials will be used for that. Private project Mars One is also known for Mars mission concepts and its colonization, but it was closed in 2019 [1]. Leading private player is aerospace company SpaceX, who plans a creation of Martian base till 2050. The company works on a launch vehicle and a starship of new generation (Big Falcon Rocket) [10]. The Interplanetary Transport System — project of the company involves the development of fully reusable launch vehicles for human transportation to Mars with the goal of self-sufficient colony establishment. The system suggests that powerful first stage will launch the second stage to the orbit — space vehicle, and then will return due to the reactive landing; refueling will happen in stages with another reusable vehicle independently. In the moment when Earth and Mars will be in the suitable position, fueled and loaded spaceship by the fast semi-elliptical trajectory will fly to Mars, subsequent flight will last for about 115 days on average. Reaching Mars spaceship will descend through the atmosphere and land using jet engine. Over time, when planets will be in positions, after refilling of propellants, produced on the surface of Mars, spacecraft could return to Earth using only its engines, without launch vehicle, carrying cargo and crew. Such races will be repeated as the colony grows [1]. Within the project the first cargo mission to Mars is scheduled for 2022. The first crew flight and base setting are scheduled for 2024. Blue Origin Company stated that its launch vehicles New Armstrong and New Glenn could be used for Mars missions as well as Big Falcon Rocket from SpaceX. That can cause a big competition in the field of Mars missions. Virgin Galactic Company has expressed interest in Mars missions [6]. Above-mentioned data shows, that setting a permanent base for scientific research of Mars and its moons is a priority. Scientists believe that despite big initial costs for building a research facility in the future, this research method will be more cost-effective than returning missions from Mars or construction of space stations-settlements for a fly-in/fly-out practice. Furthermore, Mars could be a site for ambitious scientific and technical experiments that could be dangerous for Earth's biosphere in the future. It could be a site for more fruitful commercial production of valuable mineral resources than Earth as well. Mars could be rich in mineral resources, and due to the lack of free oxygen in its atmosphere Mars could have rich deposits of native metals: copper, iron, tungsten, rhenium, uranium, gold [1].

II. MATERIALS AND METHODS

The research is mainly composed of a systematic and comprehensive analysis of the future objects, for which accounting of severe weather conditions, resource scarcity, climate extremes, ecological catastrophes are a priority. An analysis of literature, information sources, graph-analytical methods, photographic fixation, and field examination were used in the study.

III. MAIN MATERIAL

Scientists determine seven natural factors, influencing functional organization of extraterrestrial multifunctional base. Among these natural factors the first one is low atmospheric pressure and high level of cosmic radiation. Mars has an atmosphere, which gives some protection from solar and cosmic radiation. But the atmospheric pressure is 1 % from Earth's, it is too low to survive without spacesuit in it. Mars doesn't have an intrinsic global magnetic field like Earth. In addition to the thin atmosphere this fact significantly increases the amount of ionizing radiation reaching Martian surface. Mars's magnetic field couldn't protect living organisms from cosmic radiation. Martian radiation background is 2,5 times higher than on International Space Station and it is reaching the safety limits for astronauts. The second factor is water existing as ice. Pure water can't exist on the planet in liquid form and due to the low pressure ice sublime to vapor. The third natural factor is related to Martian soil, its parameters are similar to Earth's soil, plants can grow in Martian soil. Big amount of carbon dioxide in the atmosphere gives an opportunity of plant food production, and also water and oxygen production from local resources, but it requires additional experiments or an artificial soil. The fourth factor is large seasonal and diurnal variations of temperature and solar energy amount. The temperature on the surface of Mars is far below than on Earth, −63 °C in average. Surface temperatures may reach a high of about +30 °C at noon, at the equator, and a low of about −153 °C in winter at the poles. The fifth factor is constant threat of meteorites. The sixth is dust with the high level of perchlorates and plaster. Dust particles are extremely tiny to precipitate them completely, and its electrostatic characteristics can damage the equipment. The last significant factor is Martian dust storms, which have not yet been fully explored and could not be predicted with meteorological satellite [1], [11], [12], [13], [14], [15].

Dealing with most of the following factors is possible by the creation of autonomic multifunctional base in extraterrestrial environment under the surface of the planet. The best places for this are equator and lowlands. First and foremost, these are basin Hellas and valleys Marineris. Hellas Planitia is 8 km deep, at the bottom is the planet's highest atmospheric pressure, and thereby the basin has the lowest level of background cosmic radiation on Mars. The planet's minimum temperatures are in Valles Marineris, this fact expands the range of constructive materials. Its length is 4500 km, which is almost quarter the circumference of the entire planet. The width is about 600 km and the depth is 11 km.

A very promising crater for setting a base Audemans is located in the south. Valley formation is possibly related to gigantic volcanic eruption or meteorite crash. In case of terraforming the first liquid water lake will appear in Valles Marineris, but so far this hypothetical process is no more than a utopia, because there are no existing and proven technologies in the background [1], [16], [17].

Scientists also determine seven priority tasks, which should be solved at the functional organizational level of extraterrestrial multifunctional base.

These are the tasks for the first stages of creation and construction. Local energy production — could be nuclear and solar; radiation protection. Dorms and working zones could be shielded with Martian soil regolith, building them under the surface of the planet or adding special protective covers, for example, ceramic, made from local soil using 3D printing technologies; water production from ice in the subsurface layer and on polar ice caps; synthesis of oxygen for breathing, for example, from carbon dioxide in the atmosphere and ice in the soil using photosynthesis plants or more promising technologies; food production requires fertilizers and pressurized greenhouses; propellants production for terrestrial transportation as well as for space flights to Earth. This could be, for example, methane, synthesized from carbon dioxide and water, produced on Mars; setting communication between Mars and Earth. Notably, in case of successful primary tasks solution for setting an autonomic multifunctional base, number of people wishing to migrate with the opportunity to return will increase in geometrical progression [1], [18]. The organization of a crewed base on Mars is a popular theme with very interesting and well publicized project proposals. In particular, well-known project Mars Ice Home was designed as a part of feasibility study in NASA Langley Research Center in 2016 in collaboration with SEArch + i CloudsAO. During the study of Martian nature scientists discovered ice deposits under small layer of cosmic dust. It could be used as temporary material for construction of inflatable ice modules, which can withstand the pressure of 101 400 newton/square meter. Utilizing of this ice provides protection from radiation and structure support, and also helps with isolation together with carbon dioxide layer. Module has 4 levels and is for 4 crew members. It has working, recreation and sleep facilities and greenhouses. Living quarters is equipped with a bed, a table and also contains ablution unit. The construction of example is possible with 3D printing with the life cycle of 1 week. This term is short for local resources study but probably can make the main task of base creation easier. Not less interesting is the project of Martian base of 93 square meters in total, made from regolith completely, presented by Foster + Partners company. According to the concept prior to the arrival of the astronauts the semi-autonomous robots will arrive and dig a 1.5 meter deep crater. Then the inflatable modules will be delivered to Mars and placed the crater. Robots will cover them with Martian soil layer by layer. On every stage "melter" robots will fuse separate layers using microwaves, in fact providing 3D printing but in large scales. The structures would provide constant protection of the base from the excessive radiation and extreme temperatures outside [19], [20], [21].

NASA together with Bradley University set up 3D-Printed Habitat Centennial Challenge, dedicated to manufacturing a habitat on Mars. Competitors faced some strict conditions. In particular, habitats should have an area of 300 square meters. Living quarters should be for 4 persons, with the possibility of spending 1 year in it. Infrastructure and building materials were also taken into account. Finalists used completely different approaches modelling Martian habitats. In particular, the project's feature of Team Zopherus of Rogers, Arkansas is a lander module, building habitat without human help. The project won the first prize for proposal to use a moving platform to build habitat from quick-assembling living modules using local materials. The second prize won AI. SpaceFactory of New York for cylindrical shape construction convenient for 3D printing and efficient in space organization. The project provides 4-storey structure. The first floor is for garage and laboratory, the second is for kitchen and second laboratory, the third and the fourth are for bedrooms and recreation room respectively. The third prize won Kahn-Yates of Jackson, Mississippi. The complex is constructed in eight stages, the materials for its construction are retrieving from the surface, like in the first project. Module has an irregular shape, semi-transparent insertions for natural lightening, a spiral staircase. Project has garden space and dome as a protection from environment. The fourth place has SEArch + Apis Cor of New York. The authors divided modules in such way, that space, where astronauts spend most of the time would have maximal radiation protection. The construction of the module has ionic radiation shielding and natural lightening. The form of the module was adopted from north architecture and looks like winter houses of Eskimo. The dome-shaped construction saves heat, but the space is used unsustainably. Team Northwestern University of Evanston, Illinois has the fifth place with the project of spherical module and inner parabolic dome. Team relied on the simplicity of construction. Project has spherical shape. Its authors divided the hemisphere into two parts, located kitchen, ablution unit and laboratory in one part, and bedrooms in the other. Guys suggested using the inflatable construction as the basis, and 3D printer - for dome creation with the cross-beams [22], [23]. Within research and organization of Martian outpost in the conditions of increasing complexity, the results of projects competition for home of the future on Earth are of a great interest. In particular, among the nominees of annual Dezeen x MINI Living Future Urban Home Competition are design proposals with accounting of resource scarcity, climate extremes and ecological catastrophes. A good example of creation of dispersed horizontal functional organization in the conditions with resource scarcity is a project Cocoon BioFloss by architect Maria Vergopoulou made from bioplastic. The village of small cocoon houses won third prize among 400 other competitors. The project is proposed for future in which resources are scarce, forcing communities to grow their own produce. Traditional building materials would be replaced by bioplastic, a renewable material derived from agricultural bi-products. The material's ingredients would be gathered from organic substance, which would be grown by the buildings' residents.

The walls are trailed from bioplastic of natural fibres and placed on wire frames to create a protective, translucent shell. The functional and compositional center of each residence is kitchen-laboratory where bioplastic production would take place. The other rooms would be located around the kitchen. Their configuration would be influenced by the insolation and the location of natural resources.

The layout of each living cocoon is unique due to the site and the individual needs of its residents. Taking into account urban planning aspects, cocoon buildings would be eructed in a radial grid, mixing with the greenhouse areas, where the ingredients for biomaterial production would be grown. Due to its flexibility and open nature, the BioFloss material could adjust and adapt to many locations and climate conditions [24], [25].

The project Rhizome Tower: A Thousand Underground Plateaus, designed by architects Federico Tinti, Davide Mariani, Enrico Tognoni in 2011 is also attracting growing interest. In fact it is a creation of an underground city as a response to abrupt climate changes and environmental catastrophe. The main idea is to develop an underground complex that collects natural resources above and below ground creating a new life style for all mankind. The project is divided in four different parts, organized around a central core. The central core is open to natural light due to street atrium. The first part is located above the surface and contains recreational, and food production zones, agriculture fields, farms, and greenhouses. The entire facade is covered with photovoltaic cells to collect solar energy and several places are also equipped with wind turbines. The second block consists of approximately 60 levels. This block has the residential part, with a diverse range of living rooms according to family sizes. The third and fourth blocks are located in the deepest part underground. These blocks are dedicated to exploring and gathering of geothermal energy, and are used as offices, technical and service zones. At the urban planning level, rhizome is not a single element but the combination of structure-network, containing a big amount of underground complexes working together as the city [26].

Therefore, considering the above-mentioned materials, we offer a model for functional organization of extraterrestrial multifunctional base. This multifunctional crewed structure could adapt and adjust to the climate conditions due to its location in the natural formations of basin Hellas and valleys Marineris much lower than the surface of the planet, and has regolith shielding and special ceramic cover. The model can be divided into four structural functional blocks. Each block consists of a specific set of functional zones.

The conventional name of the first block is protective. It is integrated into the upper levels and provides additional protective spatial layer from unfavourable environmental factors. It consists of a transportation and laboratory zones. Without transportation zone functioning of the interplanetary transport system of spaceships for human transportation to Mars is impossible. Zone is designed for multiple uses with cargo and crew, by using special platforms on the ground, multi-level transportation tunnels, parking lots and storage area for rovers and robotics, and roads connecting this zone with the other zones of the base. A good option for organization of transportation zone is presented in the first draft version of diploma thesis to achieve a master's degree by Salo V. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", head Timokhin V., Shchurova V., KNUCA (Fig. 1.). Laboratory zone is space for collection and refining of resources from the planet's surface for wind, nuclear and solar energy production, the development of new materials from local soil using new technologies, water production from ice in the subsurface layer and on polar ice caps, synthesis of oxygen for breathing from carbon dioxide in the atmosphere and ice in the soil using new technologies, food production. Installation of photovoltaic cells and wind turbines is also possible. A good option for lab zone organization is presented in the second draft version of diploma thesis to achieve a master's degree by Salo V. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", head Timokhin V., Shchurova V., KNUCA (Fig. 2.).

Under the first block the second structural functional block is located. With the conventional name public, it is central compositional core of the base. Its open space in the form of a multi-level atrium is similar to the big vortex, slowly tapering to the bottom. It contains zones with several functions. Zone of communications distribute flows through specific routes, and also combines all main functional processes into one unit. Basically, it is a spine with conditional division into vertical and horizontal communications in zero gravity conditions. Corridors, esplanades, moving sidewalks, atriums and other features specific to urban space can be identified as horizontal communications. Stairs, lifts, elevators, ramps, escalators and other belong to vertical communications.

Informational zone contain inclusions, which helps complex to operate normally. This zone is for orientation providing, setting convenient routes of movement, receiving of relevant information and others. A big amount and high quality of informational messages and other visual, sound, light and tactile means of drawing attention are specific to this zone. Informational zone should be integrated into the structure of other blocks. Zone of consumer services is the space where retail establishments for food and household products and small area for services could be placed. Dining zone is integrated into main space as separate courts of various size and area. These zones are located on the upper levels of the block. Recreation, sports and entertaining zone is used for active and passive leisure and entertainment also. Forming places for passive leisure it is important to ensure comfortable conditions for presence and isolation from noise and visual stimuli. The equipment is important here. These are places for sitting, small sculptural compositions, greening elements. Organizing active leisure and sports zone, the space, as the rule, is visually separated from other zones of the complex using translucent barrier structures. Placing these zones on the lower levels of atrium core is typical [27], [28], [29], [30], [31]. On the perimeter of the second block the third structural functional block is located. It contains living zone and is conventionally named living. Living zone by the preliminary predictions of the scientists could accommodate 1000 people. Presumably, it is a multi-level structure, distinguished by variable scope of living rooms according to people accommodation.

The organization of living block is remarkably designed in diploma thesis to achieve a master's degree by Porada V. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", head Riabets Y., KNUCA (Fig. 3.). The proposed solution is based on the modular principle. All modules are divided into three types. These are functional modules, transitional corridor modules and gateway modules. Corridor modules form the rectangular grid-net, on the corners of which gateway modules are located, connecting functional modules together. It makes the installation on the first stages easier, makes modules universal and allows to create flexible planning solutions. Functional modules are the rectangles with shortcut corners, being delivered to Mars already assembled and are installing in the field. They have multifunctional purpose and their function changes according to equipment. Their typical sizes in meters are: 7.5x8.8, 4.5x8.8, 6x8.8, 4.5x14, 6x14, 7.5x14. The height of the most modules is 4 meters. Living modules are divided into three types: with an area of 40 square meters for one person, with an area of 60 square meters for two persons, with an area of 70 square meters for three or four persons.

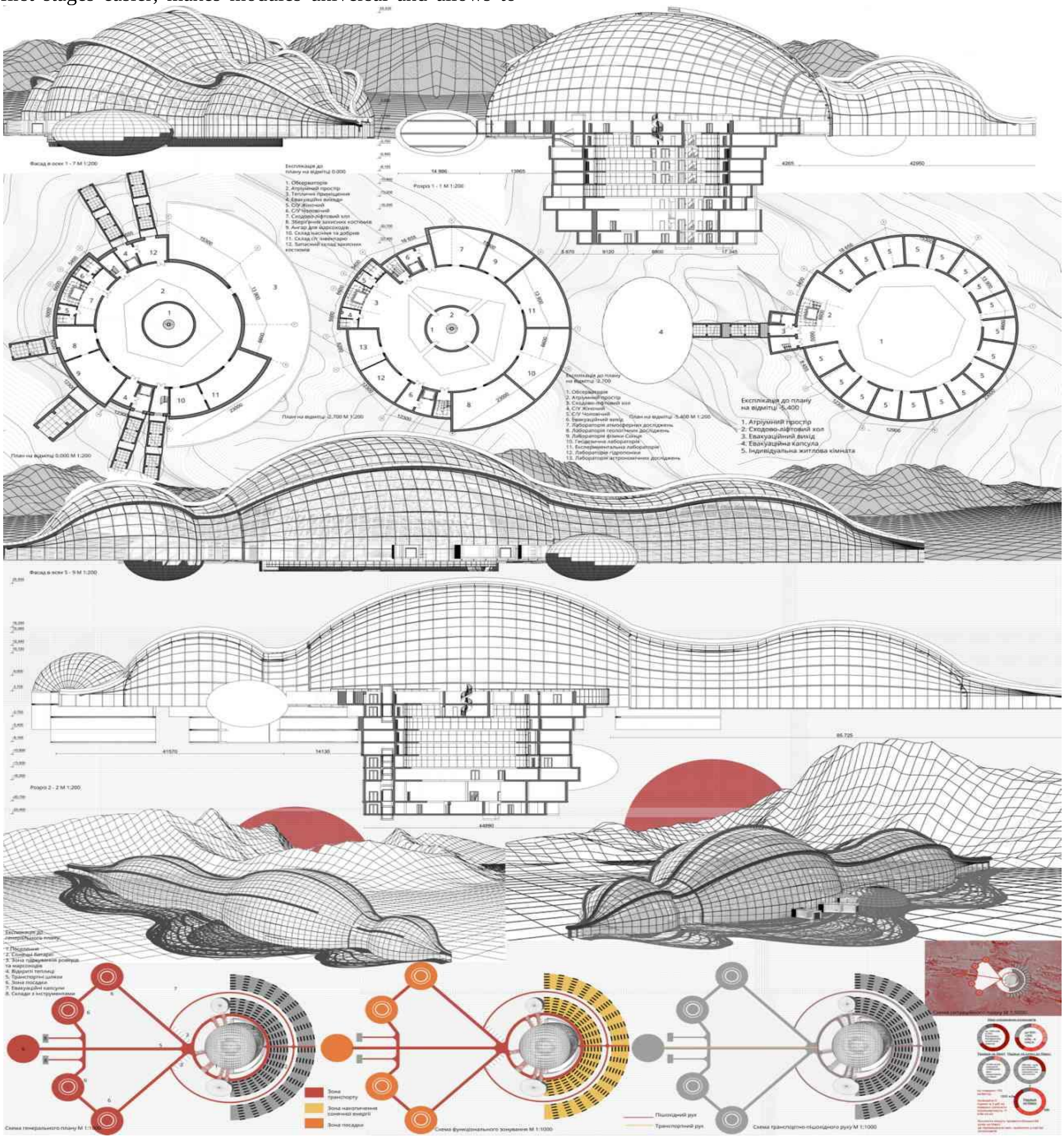

Fig. 1. Salo V. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", draft of diploma thesis to achieve a master's degree, head Timokhin V., Shchurova V., KNUCA, ver. 1

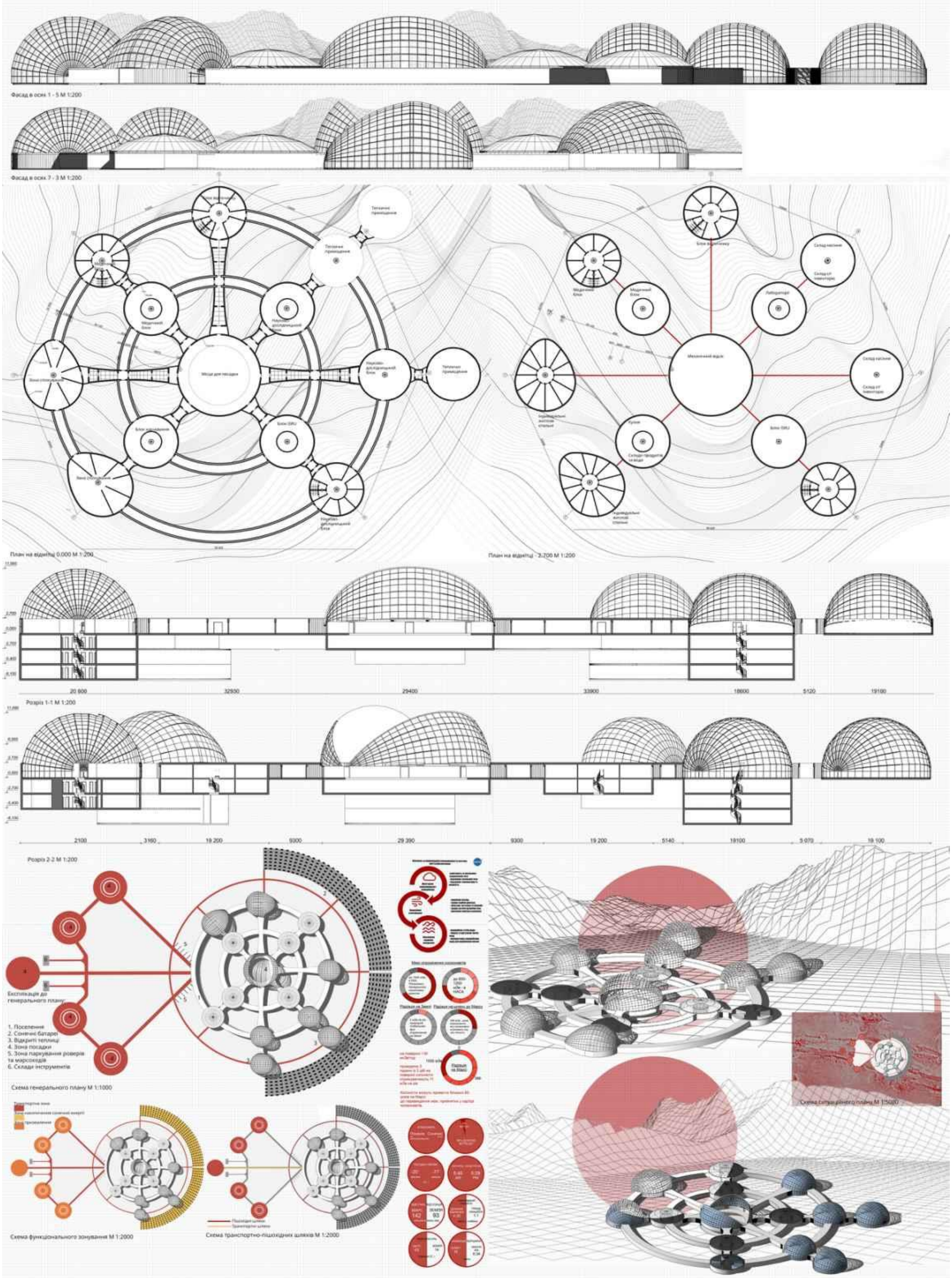

Fig. 2. Salo V. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", ", draft of diploma thesis to achieve a master's degree, head Timokhin V., Shchurova V., KNUCA, ver. 2

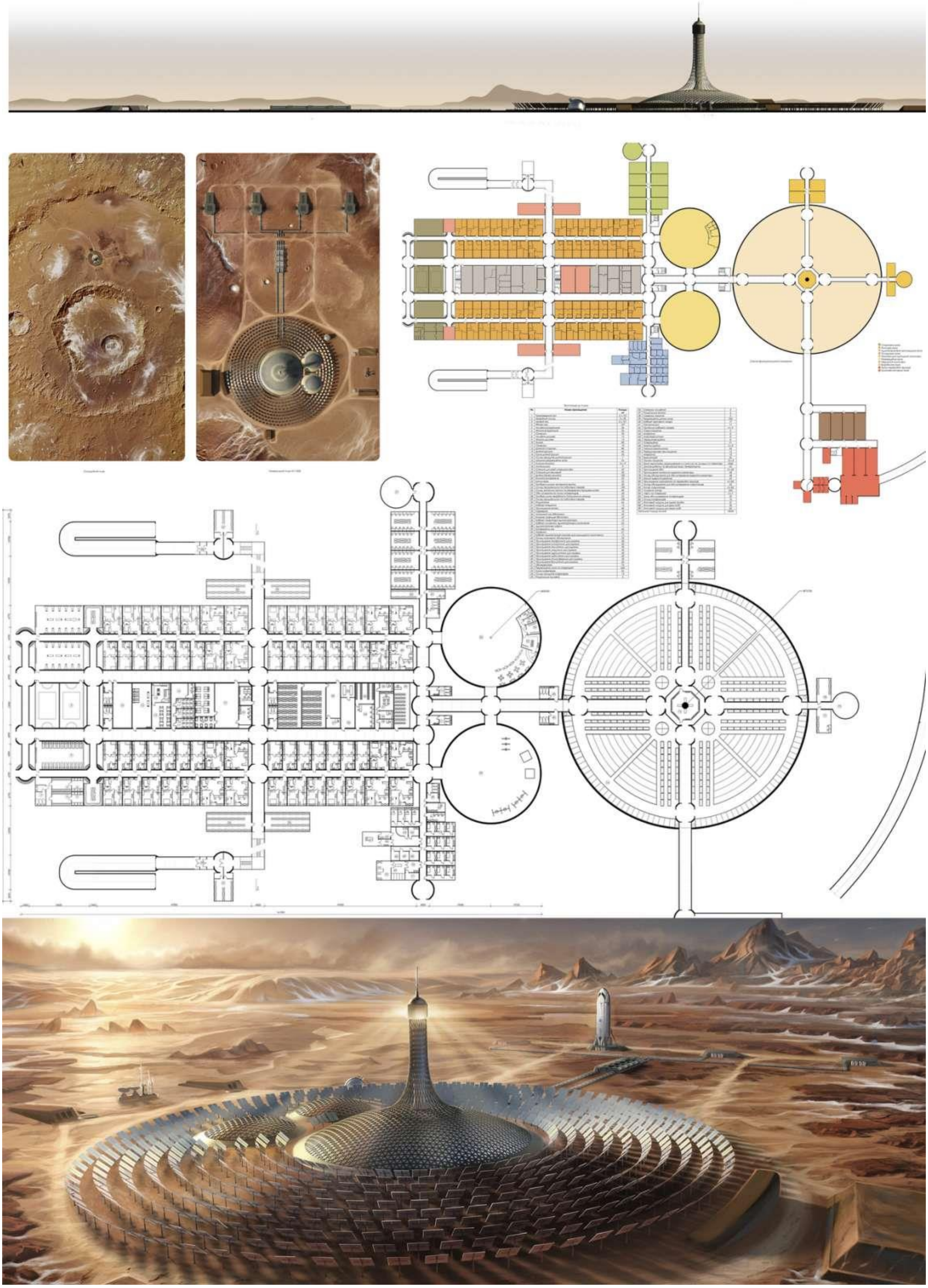

Fig. 3. Porada V. A. (2019), "Principles of functional-spatial organization of the basic settlement on Mars", diploma thesis to achieve the masters degree, head Riabets Y., KNUCA

Inner space of living module contains sleeping area, food production and dining area, work area, recreation and hosting area, lavatory. Space for communications, such as water supply, sewage, ventilation and power lines is also provided. They are connected and form integrated water, air and power supply and sewage system [32], [33].

The fourth block with the conventional name research is planned to be located in the deepest part of the complex. Being used as research, technical and service areas, it is dedicated to the study and collecting of geothermal energy. It totally depends on the processes, required for full-fledged functioning of extraterrestrial base. The option for the placement of medical functional module with space clinic is also provided in this block. As an example, the module “Space island” presented on the 43rd Arab Health conference in Dubai as concept for health management in space, can be mentioned. The module was designed by the UAE Space Agency within the UAE Mars Mission telemedicine programme. Nowadays the Ministry of Health and Prevention is working with the UAE Space Agency to develop a space clinic to treat astronauts during space flight or stay on Mars remotely using nano technologies. Telemedicine is a technology, improving treatment results and offering patients flexible scheme as to how and when they are treated. Research of the influence of extraterrestrial environment on health isn’t possible without many years of programming and experiments. That is why a programme for research of space environment is estimated at one hundred years and will be implemented alongside other international organizations, such as NASA [34]. In the fourth block emergency and storage modules, equipped with the backup generators, food and oxygen in case of main system failure are planned to be located.

IV. RESULT AND DISCUSSION

The research aims at determining of main features for functional organization of architecture of underground base on Mars, which could take into account natural and climatic characteristics of this planet. The designed model of functional organization of Martian underground base should create comfortable, fully autonomic controlled environment for human's long-term stay in extreme conditions of Martian surroundings. Main structural functional blocks of designed model and functional zones being parts of these blocks, which were determined must comply with innovative, technological, architectural and ecological requirements and conform to main activities of the first Martian settlers. Functional model of underground multifunctional base-complex consists of four basic structural functional blocks: protective block, public block, living block and research block, all of which have vertical arrangement.

V. CONCLUSION

The analysis of natural and climatic conditions of the planet Mars had revealed main factors, related to climatic features of this planet, which have primary importance and significant influence on colonization of the planet and the establishment of Martian long-term settlements. These extreme natural and climatic conditions make human's stay on the surface of Mars without protective gear and equipment impossible and require creation of fully controlled environment for livelihood of a human preserving the life and health, and creation of comfortable conditions for living and research work. The main natural and climatic factors influencing the formation of functional and planning organization of extraterrestrial Martian settlements are: low gravitational field comparing to Earth's, temperature extremes, high radiation background, absence of the atmosphere, meteorite danger and others. The most rational method for Martian long-term functioning settlement's formation was revealed and a functional model of extraterrestrial settlement was offered in the study. During the educational experimental design the most rational and promising way for Mars colonization was determined by establishment of underground multifunctional multi-level bases locating them in the natural formations of basin Hellas and valleys Marineris much lower than the surface of the planet. The proposed functional model of underground extraterrestrial multifunctional base-complex contains four basic structural functional blocks located vertically along the main vertical rod-core. The first protective block is the closest to the surface, it contains transportational and laboratory zones. The second public block contains informational zone, zone of consumer services, dining zone, recreation, sports and entertaining zone, existing and interacting into one multi-level space. The third multi-level living block consists of a living zone, and is located on the perimeter of the second block. The fourth research block contains research, service and technical zones.

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AUTHORS PROFILE

Valentyna Praslova, PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, ORCID 0000-0002-9342-6996. *Education:* Master of Architecture, Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Place of work: Certificate of docent and scientific rank of docent is appropriated Decision of the Attestation College, Associate Professor of Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Publications: 32 scientific publications (19 in scientific publications of Ukraine, 5 publications in scientific publications of other countries, 8 abstracts for conferences), 5 works of educational-methodical publications. PhD dissertation "Architectural planning organization of underground trade and entertaining complexes" (2010), Field of research: architecture, theory of architecture, artistic design, design of architectural environment.

Yuliya Ryabets , PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, ORCID 0000-0002-0357-6422. Education: Master of Architecture, Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Place of work: Certificate of docent and scientific rank of docent is appropriated Decision of the Attestation College, Associate Professor of Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Publications: 23 scientific publications (18 in scientific publications of Ukraine, 1 publications in scientific publications of other countries, 4 abstracts for conferences), 5 works of educational-methodical publications. PhD dissertation "Principles of functionally spatial organization of mobile objects of express-service facilities" (2010), Field of research: urban planning, design of architectural environment, architecture, mobile and portable architecture, energy efficient architecture, ergonomics.

Viktoriia Shchurova PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, ORCID 0000-0001-8468-3280. *Education:* Master of Architecture, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Place of work: Certificate of docent and scientific rank of docent is appropriated Decision of the Attestation College, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Publications: 53 scientific publications (30 in scientific publications of Ukraine, 3 publications in scientific publications of other countries, 20 abstracts for conferences), monography "Harmonia: Landscape. Architekture. Design", 12 works of educational-methodical publications. PhD dissertation "The architectural-planning organization of city building in zones of influence transplantation junctions" (2005). Field of research: theory of urban planning and architecture, methodological bases of forming and development of city landscape environment.

Olena Zinovieva, PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, ORCID 0000-0001-5453-2924 *Education:* Master of Architecture, Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine.

Place of work: Associate Professor, Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine.
Have Certificate of docent and scientific rank of docent is appropriated Decision of the Attestation college. Publications: 17 scientific publications (17 in scientific publications of Ukraine, 12 abstracts for conferences). PhD dissertation “Spatial Organization of City Planning Based on the Rhythmical Development Regularities” (2004). Field of research: sustainable development; theory of urban planning and architecture; methodological bases of forming and development environmental infrastructure.

Maryna Harbar PhD of Architecture, Comparable to the academic degree of Doctor of Philosophy, ORCID 0000-0002-1651-3164. *Education:* Architect, Department of Design architectural environment, Kyiv National University of Construction and Architecture, Kyiv, Ukraine. Place of work: Assistant Professor, Department of Architectural Design, Kyiv National University of Civil Engineering and Architecture, Kyiv, Ukraine. Publications: 12 scientific publications (9 in scientific publications of Ukraine, 3 publications in scientific publications of other countries, 5 abstracts for conferences). Dissertation on the theme: "Architectural and planning organization of bicycle structures in cities" (2019). Research area: architecture of buildings and structures, small architectural forms, design of architectural environment.

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