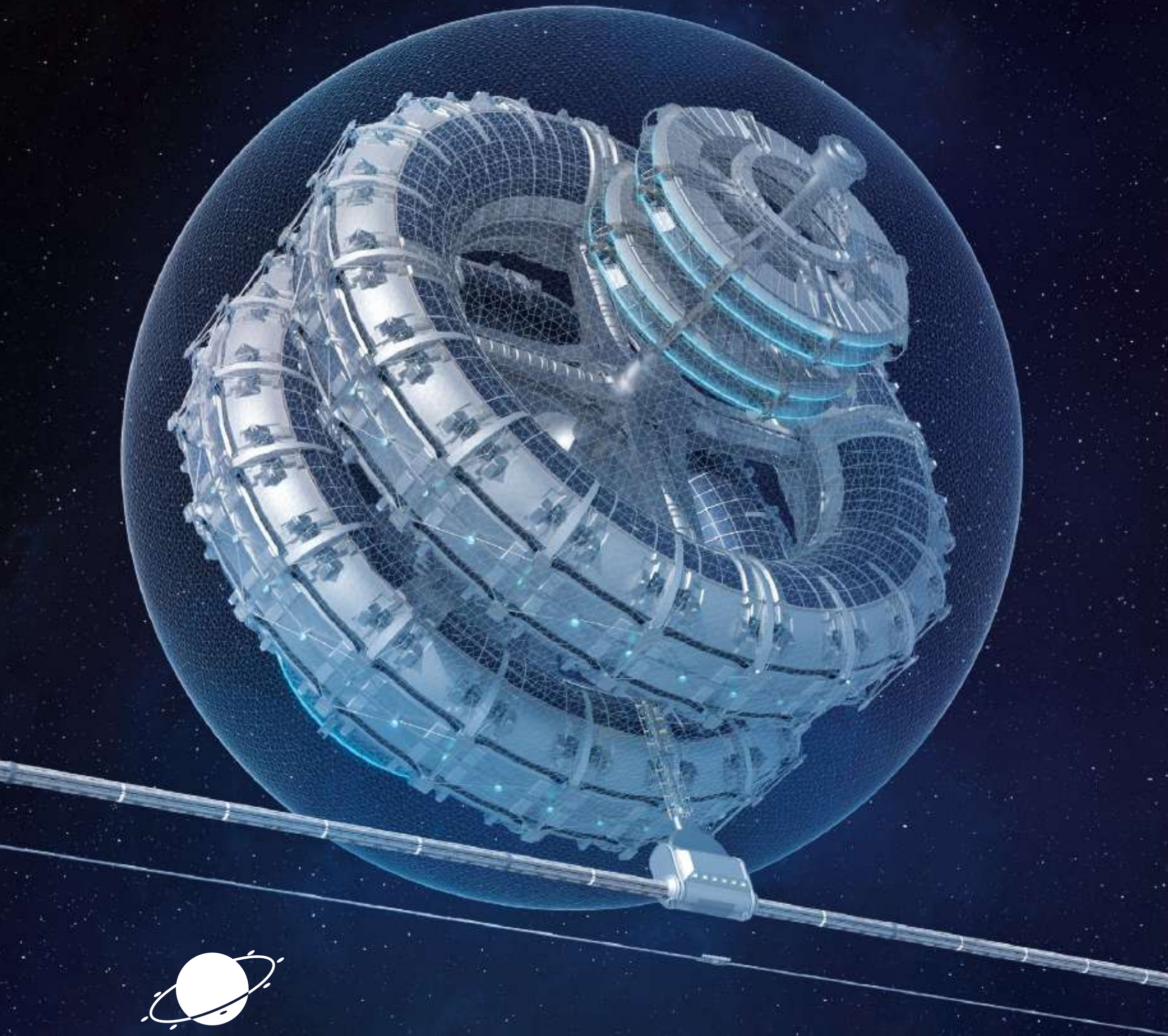

SPACEWAY

Anatoli Unitsky

System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects

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Ultimate Inventions for Ultimate World Design

Preface by Review Editor

Throughout the history of civilization, the concept of universal peace and the equitable distribution of all the resources of the planet Earth for all inhabitants of the planet has not been the leading idea of the growth and development of civilization. On the contrary, earlier and to this day, Western civilization is guided exclusively by the concept of war, the egocentric seizure of resources, and the unbridled growth of the wealth of just tiny handful under the most difficul conditions of the survival and existence of the vast majority of others.

Archaic political behaviour, growing out of total greediness and ignorance, and immoral economic practice directly led and continue to lead the planet to environmental destruction, not to mention the ongoing accumulation of warfare means, that can destroy the entire planet in a matter of hours. Trillions of dollars are annually withdrawn from the common heritage of mankind, do not serve to increase the well-being of the inhabitants of the planet, and in the literal sense of the word are thrown into a black hole in the form of irrevocable weapons debris.

G. Wallas wrote about this[1] a 100 years ago: "Men have recently increased their power over Nature, without increasing the control of that power by thought. We can make war more efficient , but cannot prevent war; we can explore the world, but cannot contrive an interracial world policy; and the same want of intellectual control exists, within each nation, in politics, philosophy, and art. We require, therefore, both more effective thinking on particular problems, and an improved art of thought, in which scientific explanation may overtake and guide empirical rules."

After 40 years B. Fuller, the remarkable inventor and visionary, who coined term Spaceship Earth, foresaw the way[2] in which ultimate "world design" could be carried out in order to eliminate the danger of self-destruction of civilization: "Both professional and amateur spokesmen for society apparently assume that the political battles will persist until man annihilates himself... We don't agree. We think that… political chaos will fade out – in ways entirely unpremeditated by political man – as the invention order looms in. Geosocial Revolution explores the possibility that the non-political surprise has already occurred and will soon be increasingly visible to all… The ultimate revolution, now to be resolved only by scientific inventing and engineering competence of the young world in general, instead of by the now outmoded and obsolete political initiatives.

Revolution by design and invention is the only revolution tolerable to all men, all societies, and all political systems anywhere."

[1] Wallas, G.: The Art of Thought. Harcourt, Brace & Company, New York (1926).

[2] Fuller, B.: World Design Science Decade, 1965–1975. https://www.bfi.o g/design-science/primer/world-design-science-decade. Accessed 15 Jul 2020.

Two ideas of A. Unitsky are ultimate inventions and cannot be copied or blocked by other patents. The priority of these inventions will remain in the history of civilization forever associated with his name.

This is Unitsky String Technologies (UST) and the double idea – General Planetary Vehicle (GPV) and Industrial Space Necklace "Orbit" (ISN "Orbit").

The first idea[3] allows connecting the "arterial" passenger and cargo flow of all continents in an integrated network, elevated above the ground, with use of the Unitsky String Technologies. This provides ultimate functional and economic efficiency with maximum throughput of global "arterial" flo

The second pioneer idea[4] also performed on the basis of the UST, opens the way for civilization to build a stationary inhabited and industrial ring in the near outer space around the planet, and also provides the transport communication of ultimate throughput between the space industrial ring and the Earth's surface.

Here one should immediately answer the fundamental question – why the "path without missiles"? From childhood, we all knew and admired only one way of going out into space – rocket! The author provides a convincing answer to this question: the tremendous inefficienc of the rocket method of transporting cargo into orbit. So, rocket transportation cannot solve the problem of ultimate "world design" to build inhabited and industrial environment in near outer space.

Ultimate author's solution allows integrating the carrying capacity of thousands of missiles in one system launch, which is impossible over to energy and ecological restrictions when using traditional rocket technologies. It is very useful to read this book already just to get acquainted with these amazing estimations.

A. Unitsky has been developing these ideas for over 40 years and is currently conducting extensive designing and experimental research. Knowing the ideas and life path of A. Unitsky for over 25 years, I must say that although the author's resources are in no way comparable to the resources, for example, E. Musk, J. Bezos, or R. Branson, but it was A. Unitsky who invented and develops the ultimate ideas of the "space ring" and the fastest and most efficien land transport in the form of string roads, including inside a vacuum pipe, by analogy with the idea of K. Tsiolkovsky.

[3] The network of string roads is being developed under the designation TransNet at the company Unitsky String Technologies Inc. – NB by *M. O.*

[4] The space industrial ring is being developed as the Industrial Space Necklace "Orbit" at another company Astroengineering Technologies LLC. – NB by *M. O.*

On the whole, these achievements make it possible to compare the selfless devotion of A. Unitsky with the life path of K. Tsiolkovsky, who also created his outstanding ultimate ideas in extremely limited conditions.

The monograph, addressed to the general reader, shows a broad systemic coverage of research and design works, demonstrates the commitment of the author and the teams led by him to the principles of global efficien , planetary safety, and future prosperity.

As far as I know, this monograph is the first in the history of technology that offers and explores quite realistic ways – principles, technologies, and constructions – for organising the life of people in near outer space. This can also largely solve the problem of preserving the natural habitat of people on the planet, preventing further pollution of the planet, leading to irreversible catastrophic consequences.

There are many important issues to be investigated and dozens and hundreds of future problems to get inventive solutions. But the principle of a self-moving vehicle up and down for the connection of the planet's surface with near space is already invented by A. Unitsky, which means appearance of hope that humanity already has the opportunity to move to a new level of its development.

It is clear that this requires the united efforts of all civilization, the planetary integration of all types of resources, the unconditional rejection of hostility and competition for resources, the postulation of the concept of "Ultimate Peace".

But it may be that precisely the invention of Unitsky's idea will become the stimulus and constructive goal for the transition of civilization to the path of non-militaristic development, the only one worthy of the human mind, to the ultimate, "eternal", peaceful branch of evolution.

In the words of the author, head of the direction of non-rocket space industrialization, inventor A. Unitsky: "We did not inherit the Earth from our ancestors; we borrowed it from our descendants. We have to work out this duty. Otherwise, we will not have any future for everyone: the Earth's technocratic civilization will disappear as a failed experiment of the Universe.

The planet is one big room that does not even have partitions. Many centuries ago the primitive people and their leaders burned fires in their caves and died of lung cancer at the age of 20. They were able to survive only due to the fact that they had guessed to move their primitive technologies (ordinary fire) beyond their home. So now we, the terrestrial civilization, should bring the technosphere outside of our home (the biosphere). All engineering solutions for this step, ensuring transition of humanity to a new stage of civilizational development, have already been created.

There is a strong belief that such a global geocosmic programme with a variety of common goals and objectives is able to unite all countries of the world and attract their resources to support this superambitious project, designed to save the humanity."

An outstanding example of global cooperation is the construction of a prototype of the future "eternal" source of energy on planet Earth – the ITER (International Thermonuclear Experimental Reactor. Also, it is associated with the Latin word *iter* – way), as a "factory" of controlled thermonuclear fusion based on the "tokomak" principle proposed back in the 1950s by Soviet physicists. The 20 bln USD project is nearing completion to become the prototype for many Suns on Earth. This means that a non-rocket construction of near-Earth space industrialization according to Unitsky's concept is also possible to save the planet and ensure "eternal" prosperity for Spaceship Earth.

I am sure that readers will find in this book many surprisingly unexpected and interesting facts, deep thoughts, and wonderful technical ideas, and possibly see a future for their activity.

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Founder and Head of the Academy
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For the Benefit of the Entire Earthlings

Preface by Review Editor

The peer-reviewed publication is a monograph "System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects". It summarises the results of the scientific and applied research projects to solve the global challenges using space- and land-based systems found on the innovative and original infrastructure solutions, which have been proposed and developed over the last 40 years by the outstanding inventor of the modern era A. Unitsky.

The current published book is the result of the next step of the development process of the research area. Presented results are utilising novel knowledge, technologies, and technical solutions, followed by the recent developments in the computer science and modelling techniques. Presented results verify usability and viability of the initial ideas and developed platforms from the new technical perspectives and using new mathematical approaches, applied to the non-rocket General Planetary Vehicle (GPV). Furthermore, the book describes perspectives and technical details of the space industry development, within the SpaceWay subprogramme.

It is clearly shown, that during the time period of 40 years there have been not just a battle for the ideas, but also construction of the solid foundation of its practical realisation. Several projects have been developed from scratch, including multifunctional models of the rolling stock of the string transport UST, which were, initially, part of the overpass system of the GPV, and several generations of the string-rail infrastructure.

Essentially, the book can be included in the list of fundamental publications related to the theories and technologies of the space exploration. Given book follows the revolutionary research works published by K. Tsiolkovsky[1] and H. Oberth[2], which describe usage of the limited in its potential jet propulsion power to explore the outer space, and initial publication of A. Unitsky "Non-Rocket Cosmonautics: Reality and Perspectives" (1990). Current edition presents breakthrough innovative approach to the near-Earth space exploration: transporting to the orbit not the limited number of cosmonauts and small amount of goods, but the manufacturing facilities of the civilization and required for its functioning goods and personnel. To achieve this aim, the innovative transportation method was proposed. Transportation system is utilising potential of the rotational motion and associated inertial forces of the massive circular construction with the changing dimensions. Inertial forces are created by rotating belt flywheels, placed in the vacuumed housing and supported by the magnetic forces. Changes in the magnetized forces are applied to the hull of the GPV to place it to the near-Earth orbits.

It is worth to mention, that from the author's knowledge, there were no potential existing solutions, despite jet motion and utilisation of the magnetic field of the Earth (which is too weak to move large amounts of goods to the outer space), until the development of the technology, presented above. Ability of creative minds and constructive thoughts to break any imaginable and, even, unimaginable barriers, as presented in the book, is truly amazing. This book belongs to the highest levels in the hierarchy of the published works in the research area due to the high concentration of the originality, scientific and technical innovations, and social and practical usefulness. Due to the large scale of the presented ideas with respect to the fundamental problems "biosphere and the humankind", the book can be added to the leading biosphere research works, which continues also the best traditions of the Russian cosmism.

From this perspective, the work is fundamentally consistent. As once A. Zasyadko (1774–1837), one of the outstanding experimenters and designers of the firs national rockets, demonstrated in 1817 in Mogilev to the field marshal Barclay de Tolly the value and power of the innovative technologies for the needs of the army and Fatherland, being guided by only his risks, fears, and at his expenses. So now A. Unitsky and his unique creative team for the benefit of the entire "army of earthlings" and the salvation of our common home – the planet Earth – here on the much-suffered territory of Belarus, nearby to the Unitsky's Farm Enterprise in Maryina Gorka near Minsk, show us all the way of overcoming the deadlock of civilizational impasse – its "sky" and "space" string technologies, equipment, and infrastructure, amazing in capabilities and significance for earthlings. He organises conferences of global significance at his expense, publishes books, shaping new scientific understanding and the humanitarian world. All of the above mentioned, undoubtedly, deserves to be given the highest assessment.

It should be mentioned, that presented ideas go well beyond the problems of creation of the technical foundation for the near-Earth space industrialization. The monograph presents various concrete proposals and options for practical development and modelling of the ecosystems of the space houses, which are based on the fundamental theories: context of V. Vernadsky about noosphere, theories of A. Chizhevsky about cosmic determinism of life, ideas of V. Dokuchaev about special status of the soils, works of V. Sukhachev about geobiocenosis, etc.

[1] Tsiolkovsky, K.: Issledovanie mirovykh prostranstv reaktivnymi priborami (Exploration of the Universe with Reaction Machines). Nauchnoe obozrenie. 5, 45–75 (1903).

[2] Oberth, H.: Die Rakete zu den Planetenräumen (The Rocket into Interplanetary Space). Walter de Gruyter GmbH & Co KG (1923).

Combination of all these ideas gives even more practical significance to this book.

I believe, that publication of the book in various foreign languages, in particular, in English, meets the needs of all countries and nations, honorable and actual challenges of concentrating joint efforts in the further development of theoretical and practical problems of creating the GPV.

It also covers the challenges of creating a higher quality in relation to the existing, fundamentally novel continental and transcontinental string-rail transportation infrastructure, more rational use of the Earth's natural resources and renewal of the existing productive forces, the unification of mankind in solving the fundamentally important large-scale tasks of universal survival, and ensuring the long-term employment of the population.

I fully support the publishing of the book in foreign languages. I consider it appropriate for all scientifi , scientifi -technical, and humanitarian criteria, its significance for solving the universal urgent problems of mankind, and the large-scale practical tasks of improving life.

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Preface to the Research Monograph on "System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects"

Antagonism between industrial technosphere and biological environment is fundamentally irremovable as long as they continue to exist in a joint space. The human-generated industry runs by the same rules as the wildlife does. It consumes resources and turn them into production and wastes. However, biowaste of some life forms is harmoniously integrated into biological chains as food for other bodies, thus performing circulation of living material within the biosphere. Industrial wastes are not included into this circulation, they upset nature's balance and lead to degradation of biosystems and the whole biosphere. The negative impact of humans on the environment increased and intensified throughout the development of industrial civilization. The author has divided this period into five technological eras which are described in detail in the relevant section of the present book beginning from the first one (Technosphere 1.0) when ancient engineers embraced fi e and cooking over it, till the present days (Technosphere 1.5) when it is suggested to explore strange and far-out Mars as a possible harbor for Earth civilization.

For sure, such a way is irrational. We have nowhere to live except our common home – planet Earth, which biosphere is inexorably destroyed by environmentally degrading plants, factories, and power stations, as well as inefficien transport systems and retrogressive agriculture steadily outgoing from natural (biospheric) technologies for agricultural production. On the other side, a non-waste industry is conceptually unfeasible, which means that only by removing it from the planet we will have a chance to recover and save the biospheric balance. Herewith, we need to maintain production of all the necessary products, including transport, energy, information, and other services, in order to provide stable being of the technogenic society, as well as its development. This can be performed only if the industry is located outside Earth bioshield and there is a streamlined complex geocosmic cargo flow between the planet habitable surface and its orbital industrial necklace. Space is for industry, while Earth is for life. This is the suggested principle which is developed within the present monograph.

The author recognized risks posed by the industry to Earth biosphere many years ago. He saw with his own eyes what we would be faced with. The Chernobyl disaster covered with radioactive cloud his home village of Kryuki, Braginsky District, Gomel Region, which was situated only 7 km away from the explosion center. Supposedly, it is the most radionuclide-contaminated place in the world because radiation level there is ten times higher than in the rest of Chernobyl exclusion zone. Generation of electric power for technosphere made this area and immense surroundings uninhabited. And the cause-and-eff ct linkage is very simple. In the region where a large industry appeared, life becomes almost impossible. And this is the case of the whole Earth, since the industrial technosphere has infiltrated almost the entire biosphere from the depths of the seas and the bottoms of pits and quarries to the upper atmosphere, permeated by aviation and space routes.

The author introduced the concept of “civilization technogenic fork” which means that today the humanity has really faced with a choice. It lies in the fact that either two generations from now we can come to the point of no return, our degradation, dying, and death, or we can stop the processes leading to global civilization crisis and pass on to the next period – Technosphere 2.1. This will allow to perform non-rocket industrialization of outer space and solve all the ecological problems on Earth while turning the planet into flowery garden where up to 25 bln of people will be able to live and work in comfortable and safe conditions.

Three terms stated in the title of the present monograph reflect the book structure and specify its problematic area. First of all, it refers to non-rocket way of space exploration. It should be noted that the history of search for vehicles alternative to reactive thrust capable of trespassing beyond the atmosphere dates back more than a century and begins with K. Tsiolkovsky’s works. Among the popular concepts of such kind, there are space elevator and electromagnetic accelerator. The development made by the author of this monograph, the General Planetary Vehicle (GPV), is also mentioned in respect thereof. The GPV outweighs the other non-rocket and even more rocket technologies in its carrying capacity and energy efficien . The relevant section of the present publication provides a detailed description of the GPV and statement of its advantages. Additional information can be found in the second part of the book titled “String Transport Systems: On Earth and in Space”, where mathematical calculations regarding operation of the GPV and its components are reported.

Unbelievable carrying capacity (10 mln tons), utmost efficienc (energy coeffi ient is of 97–98 %), low traffic handling cost (fewer than 1,000 USD/t vs. 10 mln USD/t provided by the current rockets), and usage only of electric power for access into space allow to classify the GPV as the only possible means to perform industrialization of outer space and placement of the Earth industry on the equatorial orbits.

Non-rocket geocosmic transportation with the use of the GPV is an essential requirement for extensive space industrialization. Rocket transport is not suitable of tackling such a challenging task due to its low efficienc and environmental hazard posed thereby. Thus, the GPV performing in the future up to 100 trips per year will be able to deliver up to 1 bln tons of cargo (approximately 100 kg per each earthman) and up to 100 mln passengers (approximately 1 % of the global population) to Earth orbit annually. At the same time, payload of the most powerful rocket named Falcon Heavy, which is currently employed, is only 64 tons and this is only true in case of delivery to low-Earth orbit. In other words, to deliver the same volume of cargos to outer space, it is necessary to perform more than 15 mln launches of heavy rockets year over year. Even 100,000 times less number of jet transport vehicles launched to space may completely destroy the planet ozone layer. In fact, just one launch of heavy rocket burns millions of ozone tons and makes a “hole” in Earth protective cover with the size similar to area of France.

Then, it is worth to explain why we are referring to near outer space, but not to space at large. The matter is that billions of evolution years have perfectly adapted living forms, including the man, to live in their environmental conditions. And Earth is the best place for our life. There is no any other space home for us, earthmen, in the nature. And people should live on their home planet. But the industry should be placed out of it while continuing to service technocratic needs of the civilization. Relocation of large industrial and energy productions to the orbit will resolve the majority of global ecological problems on the planet. Herewith, we will obtain access to inexhaustible energy, materials, and spatial resources of immense Space.

Hence, non-rocket industrialization of outer space is a complex programme. The author began to work on it in the 1980s or even earlier if to count from the moment when the first application was filed to get the inventor’s certificate for the GPV in 1976. The expanded presentation of the project was set in 1989 in the document prepared by Center for Scientific and Technical Creativity of Youth of “Zvyozdny Mir” (Stellar World). The Commissioner was Soviet Peace Fund. The concept was named “EcoMir” (EcoSpace), and it possesses engineering, economic, and ecological constituents.

EcoSpace Programme suggests a number of changes, including but not limited to changes in methods of space exploration and pattern of its usage. Significant changes should be also performed on Earth. First of all, it is required to reform transport logistics, urban planning, and agriculture. Creation of a unified geocosmic infrastructure network requires faster transportation process. Cargos and passengers should be distributed along the whole length of the GPV at the moment of its launching to the orbit, and then the GPV will have to deliver goods produced in space to Earth consumers. And Unitsky’s String Transport (UST) designed by the author will perform all these tasks the best way.

The industry placement outside the planet and substitution of the current earth transport with more advanced transport infrastructure communicators, including power and information ones, that are unified with the UST, will free up vast territories equal to five Great Britain’s areas now covered by asphalt and railroad sleepers. These areas may be then used for agriculture. The technology will come in useful, developed by the author’s team, aimed at obtaining rich humus from brown coal and shales which pool on the planet amounts to hundreds of trillions of tons.

The same technology can be employed for development of the world-wide environmentally safe energy production.

In order to produce energy, coal is burnt on the thermal power station of such a system. Part of the supplied coal (and/or shales) of lower energetic quality is used for humus production. Wastes from burning of the raw used for energy production, including flue gases, dust, ashes, slack, are processed the same way. Carbon dioxide gas and warmth generated in the course of the raw burning are transferred to the adjacent greenhouses while providing warming and supporting plants' photosynthesis. Humus enriches soil while specially selected bacteria make it into plant-food basis. Such relict solar biofuel power plants using Sun energy accumulated by living forms 100–450 years ago will be able to meet all the humanity energetic needs in environmentally friendly manner. Power supply for orbital industries will be performed through the systems located there which will accumulate and process Sun energy, as long as the industry is the key consumer of energy, while stars are its main source.

Agriculture should be also handled in a different way compared to present time. As it was 1,000 years ago, the key tool today is plow. However, in the author's opinion, it is totally wrong and becoming more obvious since the world population and croplands are continuously increasing. There are two kinds of microorganisms in soil: aerobia and anaerobia. First ones need air and are on the surface, the others live underground and air is awful for them. But the plow changes their places round. Microorganisms die, and their population decreases. But they perform one of the most important functions, that is processing of insoluble humus (humates) into substance feeding the plants. As a result of bacterial destruction, the soil degrades, chemical content of foods grown thereon also changes, and people can't get an adequate nutrition. Moreover, the soil is being depleted from year to year. All the vital elements are sucked out of the soil and replaced by mineral fertilisers containing only nitrogen, phosphorus, and potassium, while for high-quality healthy life we need almost all range of chemical elements which is more than 80 positions of Mendeleev's periodic table.

In this book plenty of emphasis is pointed at the issue of space colonies for personnel who will maintain the industry on the orbit. The task is to provide convenient conditions that will be very similar to the Earth ones. There have been performed relevant developments focused on arrangement of artificial biospheric ecosystems. These matters are described in detail in the respective sections. Presented is also the review of the following issues: correlation between trophic chains and biological cycles with participation of plants and animals living in artificial biosphere; vital rich soil as a space colony's immune system; treatment of water and its circulation; construction solutions for accommodation modules, arrangement of their inner space, influence of low and high pressure and Earth's magnetic field on the residents; all other aspects. Some elements of the future space colonies have been already designed and are being tested in the course of the relevant experiments. For instance, the author's team has already inspected the enclosed sewerage system where bio- and chemical wastes are transferred to soil of the greenhouse located inside the accommodation unit. There is a special bacterial association which turns the wastes into nutrients for the plants' root system.

In the near future, the author's team which currently includes more than 1,000 specialists, intends to implement the other stages of the EcoSpace programme. The self-sustaining biospheric ecosystem will be also established on Earth. The researches regarding such essential issues of the GPV designing as construction of the overpass above sea areas, as well as the GPV overpass passage through mountains in South America and Africa, are in progress now. Dynamic mathematical models of the General Planetary Vehicle are being designed. There are also developments in the field of energy industry, control and communication systems. And intermediate results of these works can be also found in the present monograph.

The task to boost public interest in the project and involve international and governmental entities in its implementation should be put a special focus on. In doing so, the International Scientific and Technical Conference on the abovementioned subject is organised every year, as well as efforts to cooperate with the competent authorities of the UN and other relevant entities are being taken. The present book will be helpful for various-skilled specialists such as engineers, designers, technical experts, as well as economists, social scientists, biologists, environmental experts, other scientists, and all readers interested in the humanity future and the Earth's tomorrow state.

The author would like to express his thanks to the joint authors, developers, and researchers whose names you will find mentioned throughout the pages as follows:

Chapter 1 – Modern Challenges of Industrial Development and Space-Directed Ways to Solve Them. The joint author is E. Petrov (Unitsky String Technologies, Inc.).

Chapter 2 – Analysing Prospects of Employment of Rockets and Non-Rocket Geospace Transport Technologies for Space Industrialization. **Chapter 8** – Features of Functioning of the General Planetary Vehicle Flywheel Propulsor and General Requirements Thereto. **Chapter 24** – Feasibility Study of the Investment Project "Non-Rocket Near Space Industrialization" as a Tool of Saving Earth's Biosphere. The joint author is A. Babayan (Astroengineering Technologies LLC).

Chapter 3 – Creative Constructivism of EcoSpace Megasystem Design and Development: Engineering Creativity with Modern TRIZ – Reinventing and Perspectives. The author is M. Orloff (Academy of Instrumental Modern TRIZ).

Chapter 4 – Key Aspects of Project and Construction Management of Astroengineering Systems. The authors are A. Voylenko and D. Kaznacheev (Unitsky String Technologies Inc.).

Chapter 5 – Water-Based Ocean Sections with Floating Overpass for the General Planetary Vehicle. The joint author is S. Artyushevskiy (Unitsky String Technologies Inc.).

Chapter 6 – Overpassing of the General Planetary Vehicle Elevated Track Structure Through the Mountains of South America and Africa. The joint authors are V. Byk and S. Zharyi (Unitsky String Technologies Inc.).
Chapter 7 – Mathematical Modelling of Flywheels of the General Planetary Vehicle. The joint authors are R. Sharshov and A. Abakumov (Unitsky String Technologies Inc.).
Chapter 9 – Use of Hydrogen in Outer Space: Past, Present, and Future. The joint authors are V. Vasilevich and V. Looksha (Unitsky String Technologies Inc.).
Chapter 10 – Methods to Convert Solar Radiation Energy into Electricity for Needs of Industrial Space Necklace "Orbit". The joint author is V. Yanchuk (Unitsky String Technologies Inc.).
Chapter 11 – Atmospheric Pressure Drop Effect Inside Residential Space Objects. The joint author is V. Zayats (Astroengineering Technologies LLC).
Chapter 13 – Options of EcoCosmoHouse Structural Solutions. The joint author is S. Zharyi (Unitsky String Technologies Inc.).
Chapter 14 – Principles of Building a Healthy Environment for Human Life, Work, Development, and Recreation in EcoCosmoHouse. **Chapter 29** – Team Matrix Formation for Success of Specific Working Conditions. The author is N. Yerakhovets (Astroengineering Technologies LLC).
Chapter 15 – Organisation of the Internal Space of Touristic Cylindrical EcoCosmoHouse. The joint authors are V. Platonava, K. Voronovich, and A. Koshelev (Unitsky String Technologies Inc.).
Chapter 16 – Principles for Establishment of EcoCosmoHouse on Planet Earth. The joint authors are S. Zharyi, A. Bonus, V. Platonova, V. Grigoryev (Unitsky String Technologies Inc.), N. Yerakhovets, I. Naletov (Astroengineering Technologies LLC), and Ye. Yermachek (Basic Project LLC).
Chapter 17 – Method of Recruitment of Specialists Ensuring the Effectiveness of EcoCosmoHouse on Planet Earth. The author is D. Kaznacheev (Unitsky String Technologies Inc.).
Chapter 18 – United Digital Economic Model for Management of EcoCosmoHouse on Planet Earth. The joint authors are A. Kushnirenko, A. Kostuk (Unitsky String Technologies Inc.), and E. Kulik (Institute of Management, Economics, and Finance).
Chapter 19 – EcoCosmoHouse Biosphere Key Elements: Integrations, Interactions, and Diversity Support. The joint authors are V. Pavlovskiy, D. Feofanov, O. Sinchuk, A. Borichevskiy (Unitsky String Technologies Inc.), I. Naletov, and V. Zayats (Astroengineering Technologies LLC).
Chapter 20 – Special Role of Food as a Building Material for Human Body in Enclosed Biosphere with Limited Dimensions. The joint authors are N. Zyl and K. Shakhno (Unitsky String Technologies Inc.).
Chapter 21 – Soil and Its Role in Enclosed System Operation. The joint authors are I. Naletov, V. Zayats (Astroengineering Technologies LLC), E. Solovyova, N. Zyl, M. Parfenchik, S. Vereshchak, A. Kostenevich, and K. Boika (Unitsky String Technologies Inc.).

Chapter 22 – Some Aspects of Maintaining Enclosed Ecosystem in Healthy State. The joint authors are V. Zayats, I. Naletov (Astroengineering Technologies LLC), A. Borichevskiy, O. Sinchuk, N. Zyl, N. Sinchuk, K. Shakhno, and T. Kurdyukova (Unitsky String Technologies Inc.).
Chapter 23 – Development of Social, Political, and Legal Foundation for the Programme of Space Industrialization. The authors are E. Petrov and A. Kazakevich (Unitsky String Technologies Inc.).
Chapter 25 – Justificat on of the Economic and Socio-Political Effec iveness of the SpaceWay Subprogramme for Participating Countries. The joint author is V. Lavrinenko (Unitsky String Technologies Inc.).
Chapter 26 – Localisation of Industrial Facilities in the Circular Equatorial Near-Earth Orbit. The joint authors are A. Kushnirenko (Unitsky String Technologies Inc.) and E. Kulik (Institute of Management, Economics, and Finance).
Chapter 27 – The Emergence of Industry 4.0 Technologies as Key Driver of Supply Chain Innovation for Geocosmic Systems. The author is M. Akbari (RMIT University).
Chapter 28 – Innovation-Driven Business Models and Novel Forms of Business Management. The joint authors are K. Badulin, M. Monchenko (Unitsky String Technologies Inc.).
Chapter 30 – Selection of Funding Sources for Non-Profit Foundation EcoSpace. The joint authors are S. Voloshina and E. Volosevich (Unitsky String Technologies Inc.).

The author is also thankful and appreciative to all who have supported the programme for many years and who continue working to ensure that each of us, as well as our kids and grandkids, cherish a desire and hope to live a bright and healthy tomorrow. This way we will be able not only to save our common home – the planet biosphere, but also enable its economic growth at an even greater pace and the industrial advance of Earth civilization.

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Glossary of Terms and Definitions Used in the Monograph

Artificial atmosphere

A specially selected gaseous mixture providing breathing and gaseous exchange for living forms under conditions of their isolation from the environment that is qualitatively similar to Earth's atmosphere. Gaseous component of the EcoCosmoHouse is artificial atmosphere

Biological balance (equilibrium)

Preserving dynamic stability of natural habitats (biogeocenoses) during a long period of time, i.e., relational balance of species' composition, their number, and productivity.

Biological diversity

Diversity of life in all its manifestations, as well as index of biological system complexity and variety of its live components. Biodiversity is considered through hierarchical levels of life arrangement with the following main categories: molecular genetics, organismic, biogeocenotical, and biospheric levels.

Civilization technogenic fork

A stage of the technosphere development when civilization faces historically important choice of two eventual action scenarios as follows:

- Earth civilization continues to rapidly develop the current technogenic vector and is limited only by the planet size range and its resources. Hereby, resource consumption goes on without any fundamental changes, since the global economy relies on obsolete and resource-heavy technologies (primarily, transport and logistics technologies in a century old state). As a result, the point of no return from degradation, extinction, and death of the human civilization will occur in about next two generations' time (in the third quarter of the 21st century);

- the beginning of near space industrialization and obtaining access to its inexhaustible resources, infinite space, matter, and energy, as well as new technological resources such as weightlessness, extreme vacuum, and cosmic rays. Mandatory requirement: ineffi ent transport and infrastructure technologies used on the planet, which pose the greatest threat to its biosphere, should be replaced by more advanced communications and ecologically oriented technologies.

EcoCosmoHouse on Planet Earth (ECH-Earth)

An earth construction intended for autonomous and timely unlimited being of the human colony of calculated number of inhabitants that provides conditions for ecosystems' development inside thereof and a range of required biospheric features, as well as being used to simulate additional technological processes to meet the human vital needs (parameters of atmosphere and environment, food resources, etc.). The ECH-Earth is a terrestrial biospheric model of the cosmic ECH regarding arrangement of inner space and all the relevant components (biosphere, technology, processes' correlation, etc.) together with enclosed circulation of the substance (living and mineral matters), energy, and information.

EcoCosmoHouse technological platform (ECH)

Construction of space facilities with inner habitable area isolated from external aggressive space environment. There is an enclosed ecosystem of Earth type inside ECH that includes artifi ially generated gravity, live fertile soil, fl ra and fauna (including microflora and microfauna), and atmosphere with controlled parameters (temperature, humidity, etc.) for autonomous eco-comfortable accommodation and working of individuals and groups of specialists, as well as settlement of thousands on equatorial orbits of the planet and in near and deep space during unlimited period of time.

EcoEnergy technological platform

Generation of "green" electrical and thermal energy with the use of the following:

- specially equipped thermoelectric power stations performing ecologically clean burning of brown coal, shales, and turf in order to get live fertile humus out of by-products of their burning;
- renewable energy sources, that are Sun energy on Earth and in space and energy of winds and sea currents;
- pairs of "hydrogen – oxygen" as fuel accumulators to complete tasks on improvement of the planet energy industry and space transportation.

EcoHouse technological platform

Ecologically oriented construction of Earth-based accommodation and industrial buildings with surrounding grounds open for external natural (biospheric) environment and fi led with natural and cultural (organic farming) ecosystems where atmospheric, soil, and water parameters are self-regulated. The soil from under the buildings is transferred to their roofs and floors and then it is enriched with live humus. This landscaping is performed under the principle of “Any building on the planet should increase areas of fertile soil and boost its fertility”.

EcoSpace

More advanced world represented by the triune of BioSpace, TechnoSpace, and HomoSpace that will generate together a system of optimal conditions for sustainable growth and further development of the Earth technogenic civilization in space.

BioSpace

Renewed and balanced planetary biospheric ecosystem that is open to space and no longer aff cted by anthropogenic suppressive impact of Earth’s technosphere and continues to develop (evolve) under the laws of earth nature. It includes the following:

- natural and cultural (organic farming) ecosystems within the land areas of the planet, including such aquatic objects as lakes, rivers, etc.;
- oceanic, marine and atmospheric ecosystems with the opportunity of environmentally friendly external control over the weather, climate, and other planet system by the natural methods;
- flora and fauna of the terrestrial and aquatic ecosystems (including microfl ra and microfauna) with preserved and currently available biodiversity;
- Earth humanity where each individual is healthy and happy.

TechnoSpace

The following newly created industrial components:

- the Earth industry on the base of new ecologically oriented technologies which components are strictly necessary to meet human’s requirement within Earth biosphere;
- the space industry consisting of energy- and resource-intensive, environmentally harmful, and other components placed out of Earth’s biosphere, which in the space technological environment acquire absolute competitive cost and qualitative superiority;
- the GPV geocosmic transport system providing environmentally clean transport logistics between the earth and space components of industrial TechnoSpace with cargo, energy, data, and passenger flows of industrial scale.

HomoSpace

Improved social and political world order subject to consolidation of the international community around a single managing center accumulating territorial, fi ancial, economic, scientifi , personnel, military, and political resources of all participating countries. This will clear the way to inexhaustible and affordable space resources and, on the basis of space-oriented economy of the Earth technogenic civilization, will create new socio-political and economic conditions to fully implement goals of the humanity sustainable development, including ensuring of social fairness, equal rights, freedoms, harmonious development, as well as the right of every resident of the planet to a decent long and happy life.

Ecosystem

Biological system (biogeocenosis) consisting of community of living forms (biocenosis), their habitat (biotope), and system of interconnections providing substance and energy exchange between them.

Equatorial Linear City (ELC)

An earth component of the geocosmic transport communication system where the GPV takeoff and landing overpass is positioned together with infrastructure necessary to perform the GPV flights and maintain global geocosmic cargo and passengers’ transportations. Such cities are the cluster settlements harmoniously fit in natural environment of the planet land and ocean areas which are interconnected with each other by Unitsky String Technologies (UST) routes and located on a strip along the equator.

General Planetary Vehicle (GPV)

Geocosmic multiuse vehicle intended for non-rocket near space exploration; it is made in the form of torus covering Earth in the equatorial plane and providing industrial cargo and passengers’ return transportations from Earth to the equatorial orbits; it is developed based on only possible (in the physics view) environmentally friendly geocosmic transport technology providing minimal energy intensity.

GreenWay technological platform

Organic farming to recreate and intensify natural biospheric processes via direct borrowing and using of natural soil ecosystems, with its microflora, microfauna, and biogeocenosis, as well as complete abandoning of the use of any synthetic chemicals (fertilisers and plant protection agents), gene modific tion technologies, and other elements of intensive agriculture.

Industrial Space Necklace “Orbit” (ISN “Orbit”)

Multiorbital transport, infrastructure and industrial-residential complex serving Earth humanity, covering the planet in the equatorial plane and representing a functional space analogue of the Equatorial Linear City, as well as a zone for protection against space threats (including meteorites) and platform for Earth civilization expansion into deep space.

Linear city

Cluster-type pedestrian urban settlement, with its surface intended for people, animals, and green areas; housing, administrative, whereby such industrial clusters are built with the use of EcoHouse ecologically oriented technologies; energy supply and heating are provided in accordance with EcoEnergy technology; food supply is connected with GreenWay organic farming technology. Transport, energy, and data communications are located above the Earth's surface at the "second level" (overpass) according to UST. Linear cities are characterised by lack of anthropogenic suppressing influ nce on Earth's biosphere, high efficiency, and autonomy of urban economy, as well as a decent standard of living and working conditions.

Space industrialization vector

Global reequipping of Earth's technosphere in order to eliminate its anthropogenic suppressive effect on Earth's biosphere through placement of environmentally dangerous and energy- and resource-intensive industries and enterprises on the low-Earth orbits. Space industrialization vector also involves ecological upgrading of some industries left on Earth and operating within its biosphere based on ecologically oriented technologies.

Sustainable development

"Meets the needs of the present without compromising the ability of future generations to meet their own needs", – this concept is formulated by the UN World Commission on Environment and Development and taken as a basis for the UN's goals and principles.

TransNet

Global communication and infrastructure landline network on the basis of the UST comprising transport, energy, data, and other lines and systems meeting the requirements of the 21^{st} century.

Unitsky String Technologies technological platform (UST)

Construction of TransNet transport infrastructure and energy information networks of a new type which are developed on the base of prestressed (string) structures by Unitsky. This platform provides all necessary communication links between objects (even continents) on Earth, between objects moving along the circular equatorial orbits in near space, as well as between objects on Earth and in near space.

Fundamental. Global. Constructive

Technosphere 2.1 – Rebooting Earth Industry Development Towards the Space Vector

1 Introduction

Now, the Earth civilization has no experience of industrial exploration of near space. It also does not know the specifics regarding the structure and operations of the space industry, which can be placed very close to the planet. The main questions for such a project include: "What part of Earth industry needs to be transferred into space?"; "What should be produced in a fundamentally new technological environment with the presence of weightlessness and vacuum and what raw materials should be used: terrestrial or cosmic?"; "Where will the main consumers of space products be located: in space or on the planet?" There are no existing solutions and distinct development directions to address these problems [1].

Development vector, which was chosen by our ancestors, has technocratic direction which cannot be changed either today or in the near future. Therefore, the technosphere created by the Earth civilization will inevitably have to be moved outside our common home – the biosphere of the planet Earth. Hence, the biosphere, inhabited by millions of species of living organisms, is not even a house, but one large communal room in which there are no partitions to shield and protect it from the technosphere. The biosphere and technosphere are antagonistic in essence, occupying the same niche in space and in time. Therefore, they must be divided in space, since the victory of the biosphere over the technosphere will mean that a human man-made civilization based on engineering technologies should disappear in the future from the planet, and the victory of the technosphere over the biosphere will inevitably destroy humanity, which created it, and even life itself on the Earth.

Environmental restrictions, the destruction, and degradation of terrestrial biota and fertile soil, which is the immune system of the biosphere, ozone layer depletion, the annual irretrievable disappearance of thousands of species from the planet, the exhaustion of non-renewable Earth resources (raw materials, energy, spatial ones), the danger of atmospheric overheating and global climate change and other biospheric challenges will lead to the need of moving significant portions of the goods production out of the planet, specifi ally, away from its living and vulnerable biosphere with limited size, into the lifeless limitless outer space.

Humanity as biological species, like any other living species on the planet, is the result of approximately 4 bln years of evolution in unique and inimitable natural and climatic conditions of the Earth. Nowhere in our limitless Universe (including on the Moon, Mars, and Venus, as well as in outer space – near and distant) can a human be provided with a higher quality of living conditions, than in his native home – the Earth's biosphere. That is why the main consumer of future space products – humanity – will be located on Earth, which was named by K. Tsiolkovsky – "its cradle" [2].

In modern systematics, the biological species *Homo sapiens* belongs to the genus People (Latin *Homo*) from the family of hominids in the order of primates of the mammalian class [3]. Man appeared on the planet and developed in collaboration with other people as a member of society, once taken out of which would mean a person cannot exist and progress, as well as meet his material and spiritual needs.

People have developed based on the Earth nature, which was created according to the laws of physics – the genetic code of the Universe. Billions of years ago, life appeared on Earth due to the number of specific factors stipulated by laws of physics, including the structure of elementary particles, atoms, and matter in general, terrestrial gravity, air chemical composition, and temperature, as well as a complex set of other specific factors. Therefore, man is only a tiny part of this physical nature. He should obey its laws, look after it, but not "bite the hand, that feeds him" – fight or destroy it. Community, unity, and harmonious coexistence of social and natural elements are the essential conditions for the sustainable development of humankind, society, and civilization as a whole.

Nowadays, nanotechnology and digitalisation are considered as the common trends, and even the concept of the "Fourth industrial revolution" (Industry 4.0) has appeared – the transition to the fully automated digital production, controlled by intelligent systems in real time, which goes beyond a single industrial enterprise, with the prospect of combining into a global network of things and services [4].

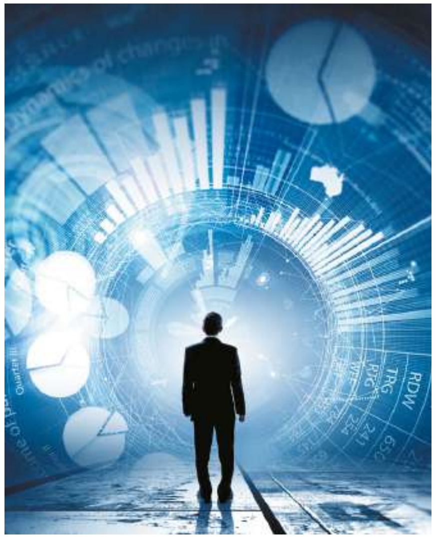
However, people are primarily material-oriented, so their use of energy, information, products, and services for their life support (food, water, air, etc.), as well as the consumption of industrial goods and services that increase the comfort of living (telephone, computer, TV, refrigerator, car, house, etc.) are associated with their ergonomics: size (average height of an earthling is 1.65 m) and body weight (average is 62 kg). Hereby, the needs of the entire civilization are determined not only by the quantity of individuals or their needs but also by their specific location across the planet and the connecting infrastructure, which includes transportation of food, energy, and information between continents, countries, agglomerates, industries (power plants, factories, workshops, etc.), as well as between personal homes and separate individuums.

Consequently, technological vector of civilization's development was chosen based on the ever-increasing material needs and their satisfaction. Thus, all that has led to the global problems of the present times. Hence, the search for inventive solutions for sustainable development of the Earth civilization is an important process for the present times and the distant future, if, of course, the biological essence of man remains the same, he will still be a person in the future, and not be turned into a biorobot or a set of digits in a computer during technological evolution.

2 History of the Earth Civilization from an Engineering Point of View – Technogenic Epochs

From the position of the Universe with billions of billions of star systems, the Solar System and the Earth as its part are a combined set of little grains of sand. It means, that in the vast Universe no one is concerned about our future except ourselves.

Human civilization differs from other terrestrial civilizations, for example, from such a purely biological civilization as dolphins. Dolphins occupied a biological



niche in the biosphere, which had remained unchanged for millions of years. They do not have technocracy, or the problems associated therewith. Although humans and dolphins are somewhat similar – those marine mammals differ from other animals by their high intellect. Besides, they have their language, even more complex than that of humans, so it is possible that the intelligence of dolphins may be higher than that of humans.

Our civilization, unlike other terrestrial societies, is a technocratic (technogenic) social system, the genesis of which is based on the development of science, engineering, technology, and production, as well as the extremely urbanized environment formed around these systems – the technosphere, which occupies the same natural niche on our planet as the biosphere – not only the surface of the planet but also many kilometres of sea and land depths and the lower part of the atmosphere. And this alien life technosphere exists and develops according to approximately the same antagonistic principles as, for example, a cancer cell in a living organism, which is booming due to the suppression and destruction of healthy cells. And now only two scenarios are possible: either the body's immune system kills cancer, or cancer defeats the body and then dies itself.

The engineering technologies (and not natural biological ones) have been formed according to the laws of macroworld (and not the micro- or digital worlds, i.e., based on physics, and not on philosophy and society). These technologies have created (in a very short time by historical standards) the modern human technogenic civilization.

The technogenic world is not just the world of science, technology, and engineering, which is not a bad thing in itself, but also the world of the material: material production and consumption, material relations, and contacts. The entire strength of modern civilization – agriculture, industry, transport, energy, electronics, computers,

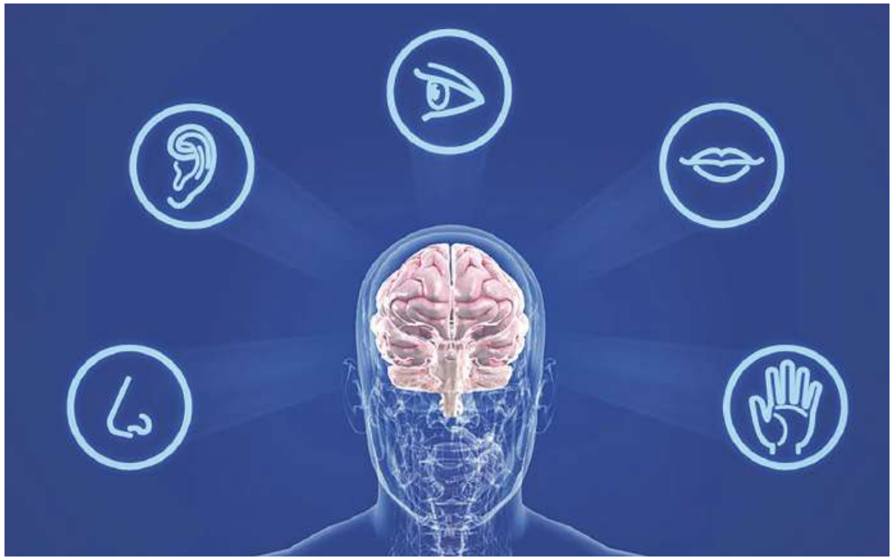
smartphones, the Internet, cities, roads, etc. – is created by engineers, not bankers, businessmen, officials poets, and philosophers. This is also true of the current (and future) global problems of humanity: if people had not invented transport, would smog and traffi jams have appeared in cities, just as cities themselves would not have appeared if engineers had not invented bricks, concrete and asphalt? If the industry did not develop, would there be oil and other wars for resources and territories? And would there have been wars if engineers hadn't invented deadly weapons?

Before engineers understand how to save the planet, the biosphere, and our man-made civilization, it is worth looking back and tracing the entire history of the Earth civilization from an engineering point of view. It is also useful to look at the relationships between two global ecosystems: the biosphere, shaped over billions of years of evolution by living nature, and the technosphere being created by intelligent man, or more precisely, *Homo technocraticus* [5].

Various types of civilizations have different definitions and various sets of features. However, the author as an engineer intends to study and analyse in this chapter the main feature of the modern human civilization: its technogenic (technological), i.e., read – engineering vector of development. Author proposed to analyse transport infrastructure, including movement of goods, people, energy, and information, as the key aspect of the study.

Presented analysis was done using systematic approach based on the engineering logic and various sources of numerical data, used in the research. Due to the large number of available data sources, author averaged out some indicators with the fundamental values being taken from the disparate and contradicting sources.

Man as a living being and as a single organism is very complex, as it consists of trillions of cells, thousands of organs and biomechanisms (up to 53 facial muscles



work only when we smile). Even the smallest component of our cells – a DNA molecule, containing billions of atoms, – is an incredibly more multi-faceted engineering structure from an engineering point of view than the entire Earth industry created by humans over thousands of years. If DNA is a million times more complex structure in comparison with, for example, an airplane [5]. However, it would be impossible to integrate various DNA macromolecules into cells, later cells into organs, which are combined in the human bodies without bioengineering communications (nervous, cardiovascular, respiratory, digestive, excretory, reproductive, endocrine, immune, and integumentary systems with millions of complex "sensors" – receptors) and with information channels from the senses (vision, hearing, smell, touch, etc.). Without the communication channels, it would be impossible to combine random sets of elements. Overall communication network of blood vessels has the overall length of about 100,000 km [6].

A. Technogenic Epoch Technosphere 1.1
(approximately 2 mln years B.C. – 5000 years B.C.)

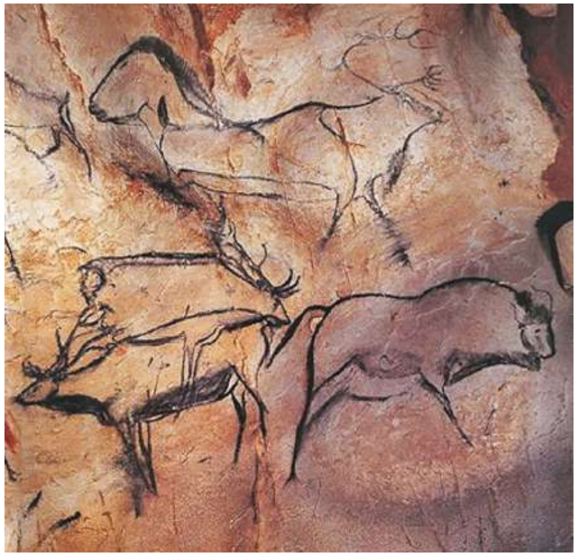
The technological vector of human development, which has now turned into an industrial one, was chosen about 2 mln years ago by our distant ancestor – primitive man. It began when not yet quite a man, but no longer a monkey invented the firs engineering technologies – lighted a fir , began to fry meat on it, dressed animal skins, and made the first primitive tools [3]. Furthermore, people have domesticated the wolf, which allowed them to improve efficienc of the hunts and won in the interspecies battle. Later on, our ancestors, the Cro-Magnons, due to their inherent and anatomical features insignificant at first glance (we can say, a physiological "defect") – the structure and location of the vocal cords – made a fundamental evolutionary leap by inventing speech. It enabled the possibility to accumulate and transmit oral knowledge from one person to the others.

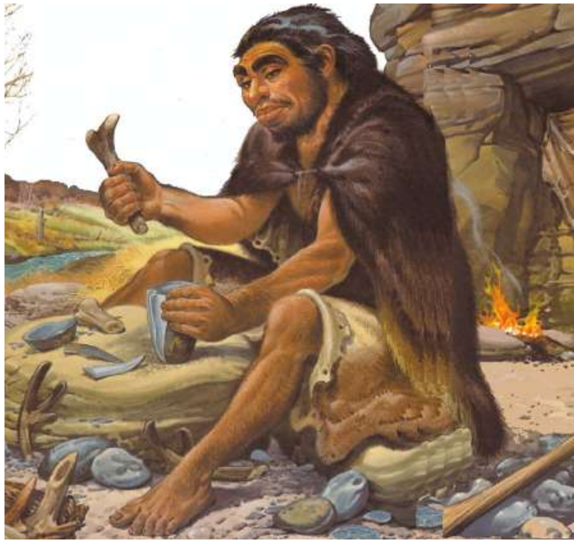
It can be identified as the first technological development level for different tribes (clans) when the concept of "humanity" had not existed as of yet. This period lasted for about 2 mln years. The communicativeness of ancient man, like any other animal, was limited in the firs epoch only by the natural parameters: muscular strength (running and walking is a material and energy component), vision, voice, and hearing (an informational component).

However, during the first epoch, scattered tribal civilizations had experienced their fi st local (house-based) ecological crises. People burned bonfi es and made skins in the caves, which acted as their homes – and died of lung cancer at the age of 20: from the unbearable smog and carcinogens contained in vital wastes from various activities. Although the capacity of the "technological equipment" – the fire – was low, about 10 kW, and the technological fuel – firewood – was quite safe

Nevertheless, they survived by taking their first technologies outside of their own homes, caves, to the surrounding environments. This technological solution required the creation of additional transport communications – footpaths. The volume of movement then was small, the distance – short: a person physically cannot carry a heavy load far. However, there was no special need for this – primitive "production facilities" were located near the cave.

Tribes became the first technogenic communities during the first epoch. Gradually, these tribes had initiated formations of nations. Initial primitive nations were united by the common interests formed around the ancient technologies. This fundamentally distinguishes us, people, for example, from the same dolphin civilization mentioned above, which developed parallel to man but did not use any engineering solutions in development.





The next technological improvements of the first epoch were initiated by the invention of the spear about 500,000 years ago, and creation of the bows and arrows in the 12th millennium B.C. (the main type of weapon up to the 17th century). With these weapons, the hunters had got a possibility to kill animals and birds at a distance of up to 150 m. The bow and the arrows are the first complex composite hunting tool, which took a whole epoch of human thinking, observation, centuries of experience, considerable mental abilities, as well as knowledge of other ancient inventions – the spears, spring traps, throwing sticks, and traps.

Ancient people began to use hunting weapons in another, already social, capacity: people chose war as a way to realise their aggressiveness in the battles for the new territories, food sources, resources, and partners. So there appeared one of the very first professions – a warrior who learns only one skill: to effectively kill others, their kind, with the help of special murderous weapons invented by primitive engineers (chopping, stabbing, striking, etc.).

Ancient people use renewable energy sources, including wood and hydropower. By following the trophic chains, it is possible to observe, that these sources represent the transmission of solar energy, which was used later on in creation of heat or was converted into mechanical energy.

The world population reached 10 mln people by 5000 B.C.

The essence of *Homo sapiens*, when interacting with the surrounding world, became two-component in those days: the first component is its biological basis, numbering about 4 bln years of evolution of living matter on planet Earth, the second is technological (i.e., technogenic) feature manifested in the engineering activity of his intelligence. The root of all modern global problems is precisely in the second component of the intelligent person. Therefore, this problem will be further prioritized in this work.

B. Technogenic Epoch Technosphere 1.2
(5000 years B.C. – the last quarter of the 18th century)

The technogenic era Technosphere 1.2 had absorbed all the achievements of the bronze, iron, and ancient eras of human history, as well as the Middle Ages. During this period, a large number of discoveries were made followed by the breakthrough inventions and creation of innovative industry technologies such as:

- ore mining and the inception of non-ferrous and ferrous metallurgy;
- blacksmithing and the first manufactories
- harrow, plough, and agriculture;
- wheel, bridle, yoke, saddle, and other harnesses, cart and horse-drawn transport, which used a horse capable of developing a power of about 5 kW, which is an order of magnitude higher than human energy capabilities;
- first glasses, microscopes, and telescopes
- lever, nail, rivet, brick, gear, bolt, nut, and on their basis – a variety of complex mechanisms, machines, structures, and tools, including those for scientific research.

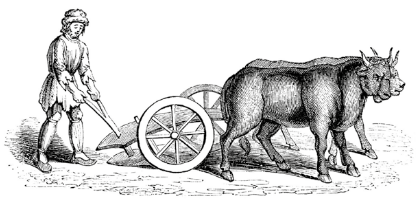
During the epoch of Technosphere 1.2, the set of sciences had appeared including mathematics, philosophy, physics, the sciences of the microworld and stellar world. Inventions included creation of the sailing fleet which enabled possibilities to make the first geographical discoveries from which, in fact, people have begun to realise themselves as humanity and civilization.

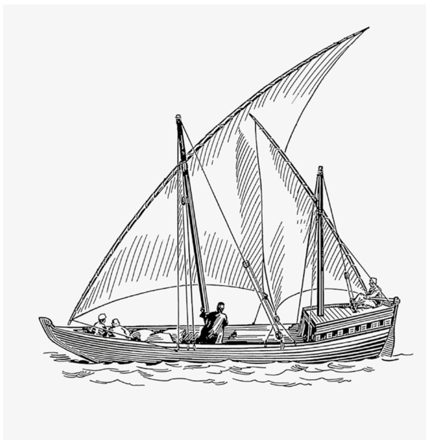
Man continued to improve the already existing and created new weapons including clubs, maces, swords, throwing mechanisms, axes, sables, daggers, rapiers, dirks, and other types of blade weapons. Moreover, they invented gunpowder and firearm (small arms, artillery, and grenade launchers), as well as the simplest powder-based missiles.

When the first states were formed, people created the army. The wars covered more and more areas and became more and more protracted and bloody – the duration of some civil strife exceeded 100 years. The loss of human life from the technocratic vector of development began to grow in proportion to this development, even when a person had not yet coined a term such as "ecology".

The inventions of the knowledge transfer technologies were initiated by development of painting, pictography, cuneiform writing, calendar, papyrus, manuscript, paper, and printing. It became possible to create, accumulate, and transmit knowledge recorded on a physical medium without the need for direct human-to-human contact, which later played a key role in the inception and development of engineering technologies and the entire Earth industry.

The development of the pack and wheeled transport on land, as well as sailing vessels on rivers, seas, and canals, had led to the formation of the first road network. Looking back by 2,000 years ago, a developed network of communications was created in Europe and Asia, including transcontinental connections such as the Great silk road, the Royal road between Egypt and Persia, communications between Egypt, Anatolia, and Mesopotamia, the amber road between the Mediterranean Sea and Baltic States, the lapis lazuli and jade roads, and the tin road between the Cornwall Peninsula in Great Britain and the Mediterranean.





The Sumerians, who invented the wheel, and then the Assyrians founded relatively long road networks about 3,000 years ago, for the construction of which special engineering troops were formed within the army, and even reference guides and road signs were developed for its functioning. A network of horse-drawn roads began to form all over the world, and ancient cities immediately began to develop along them.

Transportation volume reached millions of tons per year with the travelling distance of hundreds or even thousands of kilometres with the development of the trade

and transportation networks, even on the unpaved roads. However, the average travel speed, including the rest stops, remained extremely low – less than the speed of a pedestrian, so the long journeys used to take days, weeks, and even months.

The size of the spontaneously organised cities was determined by a single infrastructure criterion – transport accessibility [7]. Back then people understood that the comfortable travelling distance should be limited by an hour and should not depend on the weather conditions. In the ancient cities, the main transportation mode was the walks, thus the sizes of the ancient cities were limited to a couple of kilometres, as can be observed in Ancient Rome, Athens, or Jerusalem. During the Middle Ages, people had used horses and carriages, which increased the travelling speed and enabled them to cover 10 km in 30 min. Consequently, the size of cities reached similar figures, like it can be seen in Paris, Mosco , or London.

In addition to the energy sources from the first era, people started using charcoal to get thermal energy, water energy to get rotational motion in the mills, and the wind to power the boats.

By the end of the second technological epoch, the world's population reached a figure close to 1 bln people

C. Technogenic Epoch Technosphere 1.3
(the last quarter of the 18th – the beginning of the 20th century)

Main achievements of the technogenic epoch, called Technosphere 1.3, include:

- technological revolution in the textile industry, especially with the introduction of the spinning machines;
- channels construction, the invention of the water engines and later the steam engines;
- the appearance of the steam locomotives and the mass integration of railways;
- steamship construction;
- rapid development of the coal industry and ferrous metallurgy;
- the invention of the telegraph;
- introduction of the first vehicles with steam or internal combustion engines, presentation of the first power plants followed by the first electric transport – trams and electric car;
- creation of building composites and the initiating the use of the reinforced concrete and asphalt globally;
- discovery of radio waves and creation of radio;
- the emergence of the automobile industry and the beginning of large-scale construction of paved roads;
- the invention of the first tractor and the beginning of mechanization of the agricultural industry;
- the first flight by plane and the creation of aviatio
- rapid development of popular sciences (mathematics, physics, mechanics, chemistry, philosophy, biology, etc.);
- explosive growth of industry and cities, the creation of industry and industrial countries, which is still an on-going process.

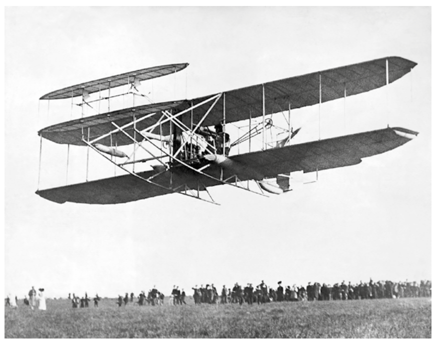
Extraction of raw materials for construction, industry, and transport had exceeded one billion tons per year, including stones, clay, sand, ore, coal, oil, etc.

The world's population reached 2 bln people.

The road network began to expand and there were qualitative changes in logistics infrastructure: the length of railways and gravel roads exceeded 10 mln km; the average speed of movement on the railway also increased and significantly exceeded the steady-state value of pedestrians or horses.

The capacity of thermal engines using fossil fuels began to grow and reached thousands of kilowatts for steam locomotives and tens of thousands for steamboats, for example, for Titanic – 55,000 HP. The annual production of such machines, including cars, began to grow rapidly and exceeded the value of 1 mln units.

The rapid development of the cities, servicing industrial areas, had begun along the railways. Traffi volumes had drastically increased to more than a billion tons per year. The scale of construction, even using simple tools like mattock and shovel, was set at a high rate even for modern standards. For example, while Russia had been analysing the need of the Trans-Siberian Railway going from St. Petersburg through Moscow to Vladivostok (the Ministry of transport offered an alternative project: to develop horse-drawn transport in the Central part of Russia), in the United States, more than 20 similarly scaled "trans-Siberian railways" were built over 15 years (from 1880 to 1895), with the combined length of 187,000 km. It created a sustainable foundation for the most powerful economy in the world [8].



More and more fertile lands were allocated for the transport infrastructure and industrial facilities. These lands were withdrawn from the biospheric processes. Subsequently, they were not used to grow green plants and did not produce oxygen, necessary for the living creatures. The volume of industrial waste released into the biosphere had increased rapidly during the given epoch. It had led to the creation of regional environmental problems, such as deforestation in the areas, surrounding cities, roads, and industrial zones, and waste heaps and smog in the cities with developed industry. There were multinational corporations and rich people who were able to concentrate huge resources in their hands to make a profit from engineering technologies, including socio-economic and military-political. This had become the main criterion for the development of both individual enterprises and organisations and most countries.

This era can be characterised with the use of a large variety of the only solar energy sources including non-renewable energy generators, which operate on the brown and dark coal, oil, and natural gas to the widespread of renewable energy from windmill and hydroelectric sources.

D. Technogenic Epoch Technosphere 1.4
(the beginning of the 20th – the third quarter of the 20th century)

The technogenic epoch Technosphere 1.4 was based on the following set of achievements and developed technologies:

- production and rolling of steel alloys;
- development of heavy engineering industry;
- construction of giant hydro-, thermal- and nuclear power plants, transnational transmission of power;
- industrial development of inorganic chemistry products and the beginning of agricultural chemicalisation;

- mass development of the automotive industry;
- the development of aviation and aircraft industry;
- invention of atomic and hydrogen bombs, as well as powerful multi-stage launch vehicles for them based on solid or liquid fuels;
- rapid development of the rocket and space industry, both for military and peaceful purposes;
- construction of the first artificial satellite of the Earth, after which a person for the first time went to near space and, late , he was able to visit the Moon;
- creation of television and electronics.

Further development and improvement took place, in the internal combustion engine and vehicles, aviation and shipbuilding industries, the formation of non-ferrous metallurgy, production of synthetic materials and composites, organic chemistry products, continuous production, and refining of oil

Large-scale construction of highways had begun. As a result, the production of new vehicles with an internal combustion engine had increased dramatically: rolling stocks (cars and trucks with the production by tens of millions a year), ships (including hovercraft and hydrofoils), aircraft, as well as airfoil boats, and surface-effect airborne ships

Access to the personal vehicles and highways had initiated creation of the American-like one-storey suburbs supported by the mortgage services, and it initiated the possibility to live dozens of kilometres away from the city, where the work is located. Simultaneously, the average speed increased to the values 5–7 times higher than the pedestrians' travel speed. The car has become the dominant mode of transport because unlike the railway, it is able to provide transportation service "from door to door" and it can be purchased by any family or by a wealthy person.

The rapid development of all sectors of the industry – from agriculture and household chemicals to electronics and automobiles – had occurred with a single goal: to make a profit by satisfying the ever-increasing and specially cultivated consumption of man-made products and services (including food) by a new kind of technocratic person – the person who consumes.

The rapid growth of a new type of technogenic employers, like – transnational corporations and oligarchs, working exclusively for profit – has led to the formation

of new goals and objectives for them: limiting the growth of the Earth civilization, including by eliminating "extra mouths". This is how the Golden Billion theory emerged.

The industrial requirements to use labour size have led to the rapid expansion of the cities up to the point of emergence of the megacities and the further growth of the world's population to 5 bln people.

The development of technology and transport – rail, automobile, and aviation – has created a powerful military industry in many countries. Two world wars were unleashed, the bloodiest in the history of mankind, as a result of which not only at the front but also in the rear, about 200 mln people were killed. Technological progress began to cause more and more tangible damage to the man-made civilization that had given rise to it.

The power of machines and equipment using fuel, the combustion products of which were released into the environment (mainly into the atmosphere), reached the values: aircraft – tens of thousands of kilowatts, power plants – millions, and heavy launch vehicles – 100 mln kW.

This era can be characterised with innovative energy source invention and its wide application in the energy generation units – nuclear power. Besides, it is possible to observe the widespread use of renewable energy generators operating on solar and wind power. However, despite ecological benefits, majority of the renewable generation units are integrated into the residential areas rather than the industrial sector due to their low reactive power generation capabilities and instability.

E. Technogenic Epoch Technosphere 1.5
(the third quarter of the 20th century – present)

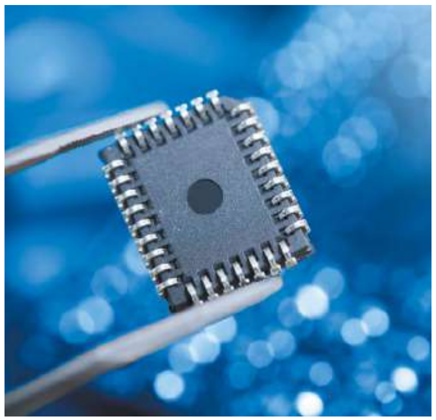
The key achievements of the technogenic epoch Technosphere 1.5 include the following steps:

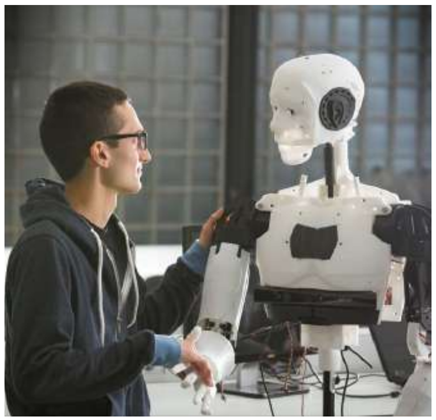
- rapid development of the electronic industry;
- creation of microchips, microelectronic components, and personal computers;
- the emergence and large-scale spread of the Internet and wireless communications;
- intensive development of fibre-optic communications and telecommunications;
- development of complex computer software;

- widespread use of robotics;
- large-scale production and processing of natural gas;
- comprehensive provision of informational services;
- the emergence of 3D Printing and Artificial Intelligence

Terrestrial population has reached a total figur of close to 8 bln. There is ongoing accelerated urbanization with the growth of urban agglomerations into megacities having a population exceeding 10 mln people each. Nowadays, there are 16 megacities built around the world. The urban population has begun to predominate over the country population exceeding 50 % mark in 2007. This epoch is marked by the birth of a new kind of human being "tech consumer" – "man of asphalt and smartphone", which has an atrophied connection with the wildlife, i.e., with the Earth biosphere.

The construction of motorways is progressing rapidly at present, and a network of high-speed railways is developing. The total length of the roads globally, including unpaved ones, has exceeded 65 mln km [9] (of which more than 35 mln km is paved).





This process leads to the development of multiple-hours and kilometres-length traffi jams. As a result, the average speed of traffi in megacities drops sharply to the speed of a pedestrian. It creates excessive gas pollution and smog, consisting of a mixture of exhaust gases, tire and asphalt wearing process, as well as industrial gaseous and dust wastes, which might contain more than 100 various carcinogens. A sharp deterioration of life's quality in cities has begun, including the deterioration of transport accessibility. These processes require people to spend 3–5 hours daily to get to and from workplaces, which is a signifi ant portion of the day. Additionally, deteriorated air quality has created unsafe conditions for people and pushed them to constantly wear a face mask, even before the COVID-19 pandemic.

Transport can be seen as the most dangerous invention in the history of technology. Currently, approximately 1.5 mln people die on the world's highways alone annually (some of them die in hospitals from post-accident injuries and therefore do not fall into the traditional statistics), and about 10 mln are getting injured, disabled or crippled. This is only direct obvious damage lying on the surface. Several times fewer people die every year in local wars that did not stop for a single moment on the planet, as well as from man-made disasters and the activities of terrorists. If there is a third world war with the use of nuclear weapons that can bring untold misery and losses to humanity, then transport will also be to blame for the huge number of victims. Nuclear warheads will be delivered and dropped on peaceful cities by vehicles invented by modern engineers – missiles, planes, ships, and submarines.

This epoch can also be described with the increasing use of mineral fertilisers and pesticides in agriculture, which has led to a catastrophic deterioration of the biogeocenosis of soils and food grown on them. In the biological processes, food acts as a source of energy and as a building material for cells and organs – our cells live on average for about six months, then die and get removed from the body, and new ones replace them. Chemical composition of the food-based solutions includes more than 70 elements in the form of a variety of organic compounds taken by plants from the fertile humus contained in soils. However, degraded soil cannot provide missing nutrients. To avoid a starvation problem, humanity has started to widely use biological "crutches" – genetically modified foods and dietary supplements (biologically active supplements). In fact, the food genocide of humanity has begun, again for the sake of easy profit – you can earn and make huge rofits from this

Pharmacology has received a powerful boost, again for profit – healthy people are not needed here, since it is from a chronically ill person that you can earn more. Genetic engineering began to develop rapidly. Man, as an engineer, began to “improve” living organisms – something that he was not able to understand and comprehend due to the limitations of his mind and knowledge. Just as he could not foresee the unpredictable long-term results of such activities and the harm that could be caused to humanity in the future (for example, the spread of coronavirus; and in the context of what has been said, it does not matter whether it is of natural or artificial origin)

There is an on-going formation of the ideology, which declares the limited carrying capacity of the planet, allegedly exceeded already. The civilizational values are being reviewed and shifted in the field of maximising the use of new and surplus wealth (new house, new car, new computer, new smartphone, new clothes, new shoes, etc.), as well as new services: transportation (a permanent increase in the length of roads and travel distances by private transport), energy (construction of new thermal power plants, including nuclear power stations) and information (Internet, mobile phones, TV, ubiquitous digitalisation).

The transition of consumers from material to virtual digital-based reality is widely cultivated, as it is easier to earn a large profit there with fewer costs. In addition,

the cult of emotional marketing is being created, which turned the vector of excessive consumption into an information component: the market began to sell not the product itself, but the emotions from the products. This approach has dramatically reduced the quality of products with new products having lifetime of 1–2 years with the idea of continuous replacement by a new one. This transition proportionally increased the resource intensity of all industries and raised the technogenic footprint for the biosphere.

The widespread digitalisation of society only aggravates the global problems of humanity, since any digit is based on the material component of the technosphere. In particular, the capacity of two power plants like the Chernobyl Nuclear Power Plant is already being spent on supporting the global Bitcoin network [10].

More than 5,000 satellites have already been launched to the Earth orbit to ensure the functioning of the Internet and mobile communications. Meanwhile, in the near future, only Elon Musk alone (based on the global number of launches) is planning to put into orbit more than 40,000 additional satellites, which will require about 700 launches of Falcon 9 – heavy launch vehicle – with 60 mini satellites [11].

The modern era is declaratively proclaimed as the epoch of saving resources (energy, raw materials, mineral, spatial, financial, labour, time, food, etc.) without a systematic understanding of the general aim of these savings.

So, over the past century, the world’s population has grown by six times, followed by GDP growing by 20 times, which has significantly increased the demand for some resources [12].

At the same time, humanity has entered the epoch of expensive resources. Furthermore, increase in the world’s middle-class population by 3 bln people in the next 20 years will only increase the resource demand. Meanwhile, the search for alternative sources of mineral sources and energy-contained materials, energy, food, and water will become more difficult and very expensiv

A shortage of resources or increase in prices for one type of resource will be shared by the others. According to some analysts, an attempt to meet the progressive demand by proportional growth of production will require more than 10 tln USD of investments in the world economy annually in the near future [13]. This can become another trampoline to the point of no return for the Earth technogenic civilization and its existence in general.

At the same time, services are not widely considered as the critical resource, among which transport and logistics are the main ones – our civilization cannot exist without them. However, very few studies have been covering not the specific regional network, but the optimised worldwide solution for the planetary transportation systems.

In fact, roads and infrastructure, power plants and power lines, communication satellites, and the Internet are created for providing humanity with qualitatively new transport, energy, and information services, which in theory should be more efficient, affordable, economical, environmentally friendly and cheaper (less resource-intensive). Additionally, they are aimed at maximising the savings of time, which is the most valuable and non-renewable human resource.

Engineers also had a dream: to use the energy of the singularity – the energy of thermonuclear fusion (the fuel for it is light chemical elements, including hydrogen – they were formed about 14 bln years ago during the Big Bang). However, there are no examples of solutions, which utilise this type of energy.

This dream, for which humanity spent 70 years (for example, it took the same time to build communism in the USSR) and tens of billions of dollars, is unpromising from an engineering point of view, since it has already been implemented in a natural thermonuclear reactor – the Sun. Unlike Chernobyl and Fukushima, the Sun has not had a single accident in 5 bln years of operation; there will be no accidents in the next 5 bln years. It is much easier to convert the fusion energy obtained in the Sun into electricity than in a man-made thermonuclear reactor (tokamak), therefore people have been using solar power plants for a long time, but whether tokamaks will function at all is still an open question.

3 Scenarios for Development of Human Civilization

This section discusses two scenarios of further development of civilization, considering the available choices at the present moment at civilizational technogenic fork.

A. Scenario No. 1

The Earth civilization continues to rapidly develop its technogenic vector that became industrial two centuries ago. It is limited only by the size and resources of the planet. At the same time, resource consumption stays constant, since the world economy relies on outdated and resource-intensive technologies. For example, transport and logistics services, being one of the fundamental elements of the economy, are using century-old technologies:

- infrastructure technologies include the construction of conventional roads (motorways and railways) for the historically formed rolling stock, development of traditional buildings and structures (using concrete and steel), usage of traditional thermal power plants that operate on coal, gas, or nuclear fuel;
- high-speed vehicular technologies, which are presented by the cars, electric vehicles, railway trains, and Maglev-based solutions for land-based transportation, jet aircraft – for flying between Earth's locations, and multi-stage rockets for space transportations.

Such conventional infrastructure facilities (including airports and cosmodromes) traditionally require land to be developed. They also pollute the land, air, and water with billions of tons of toxic and carcinogenic wastes. Additionally, the research studies demonstrate that in the USA more than 365 mln animals are being killed in road accidents annually [14]. Meanwhile, studies related to the European Union highlighted that up to 27 mln birds are killed on the roads every year [15].

Analysis of the worldwide statistics of infrastructure construction shows that the extraction of minerals and construction materials has already exceeded 60 bln tons per year (about 8 tons for every inhabitant of the planet) and continues to grow. It includes ore – more than 10 bln tons (including iron ore – 2.4 bln tons and copper – about 4 bln tons). Annual cement production has reached 5 bln tons, and concrete production has exceeded 30 bln tons [16]. Production of construction sand has exceeded 11 bln tons on the annual scale, crushed stone, including that for the production of concrete, has exceeded 20 bln tons. The number of earthworks (sometimes involving the movement of soil for tens or hundreds of kilometres) in the construction of roads, infrastructure objects, factories, power plants, buildings, structures, and other objects has exceeded 30 bln tons per year [17]. As there is a lack of available statistical data, author estimated that the volume of overburden removing and reclamation operations in the extraction of mineral raw materials exceeded 400 bln tons per year (with an average overburden rate of 7 tons per ton of extracted mineral raw materials).

Thus, on the planet annually, about 500 bln tons of minerals are extracted, processed, and moved over an average distance of several tens of kilometres, of which more than 400 bln tons are ordinary soil, including rocks that go to the dump pit. At the same time, certain raw materials and resources are transported using inefficient and environmentally dangerous transport over distances exceeding 10,000 km.

The total installed capacity of equipment on the planet using fossil fuels, including boiler houses, power plants, and all types of vehicles (road, railway, aviation and sea transport, missiles, etc.) exceeded the value of 100 bln kW.

Energy raw materials are extracted in amounts exceeding 15 bln tons annually, from which coal is about 8 bln tons, oil – 4.5 bln tons, and natural gas, including shale one allocates more than 3 bln tons. The fuel is then burned using air, as it is the cheapest source of the main oxidizer – oxygen. The global consumption of oxygen for this purpose is close to 50 bln tons per year. While in the pre-industrial era, this oxygen was used for completely different purposes – for natural processes of oxidation (for example, due to this, iron ore deposits were formed), which are occurring worldwide. Thus, the Earth industry currently burns more than 1/3 of the oxygen produced by the biosphere annually in the amount of 145 bln tons [18]. Considering the current growth rate, this value will soon reach the 50 % mark, which author considers as a critical point.

Meanwhile, the productivity of the biosphere is only 220 bln tons of living matter per year (in terms of dry matter. In its natural state, this will be more than 1 tln tons, since all living organisms consist of water by 70–90 %). Studies also showed that the productivity of the biosphere is directly related to the content of free CO_2, besides, it experiences an annual defic t of carbon dioxide contained only in the Earth's atmosphere, in the amount of at least 200 bln tons [19]. Consequently, the increase in carbon dioxide in the atmosphere, which everyone is so afraid of, will lead not to global

warming, as the primary issue, but to growth in oxygen production by green plants, as their biomass will increase. This means that it makes no sense to limit CO_2 emissions (according to the Kyoto Protocol) since excess carbon dioxide will bind plants while increasing agricultural productivity. This process will further help to address the food problems of humanity.

In fact, rocket transport causes the largest damage to the environment. A single launch of a heavy launch vehicle burns a "hole" the size of France in the planet's ozone layer (with a chemically active, high-temperature and high-speed jet stream), and up to 1 mln tons of ozone per ton of payload delivered to orbit is destroyed depending on the fuel used [20]. Since the mass of atmospheric ozone is about 3 bln tons (0.000064 % of the mass of the planet's atmosphere) [21], the entire ozone layer and, accordingly, life on the planet will be destroyed when only 3,000 tons of cargo (or 0.38 g of cargo for each inhabitant of the planet) are put into orbit in a short period. This corresponds to 100 launches of Space Shuttle rockets.

The direct damage caused to the planet's biosphere when launching a launch vehicle is about 100 mln USD for each ton of payload. Consequently, space carriers should be charged the appropriate biosphere environmental tax, and the cost of rocket geocosmic transportation, for this reason, cannot be decreased below 100 mln USD/t [22].

Supersonic stratospheric aviation also has a signifi ant contribution to the destruction of the ozone layer with its high-speed and high-temperature exhaust gases from jet engines and with the creation of inversion trails, which might have a length of thousands of kilometres (in terms of flight range). Exhaust gases are preserved for a long time in the form of stratospheric clouds, the surface of which catalyses reaction of the ozone decomposition. Moreover, such clouds are spread by the stratospheric wind over the entire surface of the planet, including the Arctic and Antarctic areas (ozone holes there can reach an area of more than 20 mln km^2), then settle on the surface of the planet throughout the year. Impact of the rockets and jet planes can be seen from the fact, that ozone layer holes had not been recorded by scientist before the beginning of the rocket and jet plane epoch.

The power of solar energy reaching the Earth's surface is about 200 tln kW. However, the ozone layer traps almost 3 % of the solar energy [23] in the most life-threatening ultraviolet spectrum, i.e., the power capacity of this "thermal blanket" of the planet can be estimated at 6 tln kW. This fact means that the destruction of only 1 % of the ozone layer (and this means the delivery of 30 tons of cargo by a heavy rocket to orbit) increases the terrestrial solar radiation by 60 bln kW, which had previously been trapped by the ozone layer high in the atmosphere.

This power, which will heat the surface of the planet, significantly exceeds on-stream capacity of the entire terrestrial industry, including power generation sector and transport. Therefore, heavy launch vehicles are the biggest threat to the planet's biosphere. They are the main cause of global warming, not freons, coal-fired power plants, industrial CO_2 emissions, or cattle that emit allegedly too much methane [24], as is generally believed.

Thus, plans to relocate earthlings to Mars and other planets using Elon Musk's rockets, which have become especially popular in recent years, are not only utopian but also extremely dangerous for humanity.

The average power of solar energy reaching the surface of the planet (taking into account its shaded side) is around 350 W/m^2. The average thermal power of the annual continuous combustion of all industrial fuel in the atmosphere (about 15 bln kW), reduced to a square metre of the planet's surface, is 0.027 W/m^2, which is 1/12,500 of the similar power of solar energy supplied to the planet. This additional energy is able to raise the temperature on the planet by not more than 0.02 °C.

From the discussion above, it can be determined, that mineral resources are not the main consumed type of resources, as it is commonly discussed. The following resources are consumed in larger quantities:

- air-based oxygen, including its derivative – ozone;
- the fertile surface area of the Earth in square metres where green plants can grow producing oxygen and utilising atmospheric CO_2;
- humus (live fertile soil);
- the soil that lies under the fertile soil (and sometimes covers the extracted raw materials with a layer of a kilometre or thicker).

It is in the excessive and increasing consumption of these resources, which are an integral part of the common biosphere heritage of mankind (moreover, the entire Earth civilization, and not the world elite or a single country), that the root of all global problems of humanity lies. Consequently, an industrial environmental tax must also be levied for their irrational use. In particular, additional atmospheric CO_2,

the greenhouse effect, hundreds of toxic substances and carcinogens are the result of the burning oxygen process from the atmosphere and further releases of high-temperature combustion products into the environment.

The weakening of the human immune system and most diseases, in the form of epidemics and pandemics, are the consequences of depletion and weakening of the immune system of the entire biosphere, i.e., of the living soil and its thousands of species of beneficial microorganisms (up to 100 bln per kilogram of soil like chernozem). They feed, give to drink, and even treat us not only in the soil (through healthy food grown on it), but also in our intestines. It is there that a huge army of microscopic workers (there are several tens of trillions of them in each person) processes and converts food into the state and type that can be assimilated by the animal and human body. Fertile soil is the basis of all any life on the planet's land surface. It is not only more and more increasingly "rolled" down into asphalt and "buried" under sleepers (today it is the area of fiv Great Britain's territories [5]), its infusive force is being killed by ploughing, mineral fertilisers, pesticides, herbicides, other toxic chemicals, and hundreds of carcinogens from exhaust and flue industrial gases.

A human consumes an average of 250 kg of oxygen per year for breathing. Simultaneously, more than 2,000 kg of various fuels are burned per person on the planet annually. This process consumes about 7,000 kg of oxygen (i.e., 28 times more than we need to breathe) contained in 35,000 kg of air, which is equivalent to 28,000 m^3. All this air is passed through high-temperature combustion in boiler and power plant furnaces, as well as in internal combustion engines (from cars and ships to airplanes and helicopters). In the currently used burning processes, oxygen from the air is simultaneously burned out and replaced with hundreds of various toxic substances and carcinogens, including CO_2 and methane, which are harmful to an earthling, as well as to the biosphere in general. These gases are exhaled, for example, by cows.

In the 21st century, our civilization can be put to the last point in an experiment that has been continuing on Earth for thousands of years, similar to the experience in a Petri dish, however, not in a local, but in a planetary ecosystem. It is known that mold inevitably dies in a short time after eating up limited resources and polluting the entire space with waste products. The main reason is that there is no cycling of matter, energy, and information in the dish, and there are no trophic (food) chains when one species of living organisms feeds on other species and their waste. It is as a result of these processes that have been going on continuously on the planet for billions of years of evolution, that the main biosphere waste (humus and oxygen) is formed. A dead Petri dish returns to its original dead state according to the second law of thermodynamics – the increase in entropy of any closed system.

The author called the described scenario Civilization-21, because it happens within the 21st century. As it was proposed, in about two generations (in the third quarter of the 21st century), the terrestrial experiment "technogenic vector of development" may end with the point of no return. Author thinks that after passing this point, nothing will be able to save the Earth human civilization from degradation, extinction, and death.

B. Scenario No. 2. Reloading of Technosphere

Technogenic Epoch Technosphere 2.1
(the second quarter of the 21st – the end of the 21st century)

Earth engineers are finding solutions to provide the Earth industry with access to the unlimited resources of outer space. These resources include infinite space, matter, and energy, as well as the new technological conditions: weightlessness, deep vacuum, and cosmic radiation. At the same time, inefficien existing transport and infrastructure technologies, that additionally pose the greatest threat to the biosphere, should be replaced by more advanced transportation means.

In meeting the mentioned requirements, humanity will have unlimited opportunities for further sustainable development both in space and in time, along

the technological vector, which we, now living, as noted above, have not been entitled to cancel. The solutions necessary for tackling this problem were already discovered by the author of this study more than 40 years ago, and they are perfectly simple.

Solutions for terrestrial conditions. The best option, from the author perspectives, is Unitsky String Technology (UST), as well as Equatorial Linear City (ELC) with a take-off and landing overpass for geocosmic string transport – the General Planetary Vehicle (GPV) – with a length of just over 40,000 km [1].

The UST, which has the maximum characteristics allowed by physics (in terms of efficien , economy, environmental friendliness, safety, resource intensity, etc.), will fully supply the annually growing transport needs of humanity [20]. According to the UN, the people's transportation needs by the middle of the 21st century should increase by 2–3 times with a subsequent significant increase in the speed and distance of the travel [25, 26].

The UST system has two significant benefits

Firstly, freight roads will enable a low-cost transportation mode to currently inaccessible mineral resources, located: in mountains, tundra, vast swamps, and permafrost; on the shelves of seas and oceans, including the Arctic ocean with its enormous resources; deep in vast deserts, islands, or continents, such as Australia. It will make these resources more accessible and less costly, which will establish sustainable development of the world economy.

Secondly, cargo-passenger string-rail roads will allow creating an extensive, about 25 mln km long, global network of transport and infrastructure communications TransNet using fewer resources (materials, energy, land, financial, labour, etc.) and with significantly lower cost. TransNet will combine the transportation network with energy and information networks. Automated control systems for TransNet will be integrated into the residential infrastructure of linear cities, whose clusters will also generate clean energy and information for their own needs and the needs of third-party users, including using Blockchain technology.

TransNet network will include in total about 5 mln km of high-speed (speeds up to 500–600 km/h) and hyper-speed forevacuum lines (1,200–1,500 km/h) being

placed above the ground, underground, and underwater. The remaining 20 mln km will be dedicated to the urban, suburban, freight, and passenger routes with the travelling speeds of 100–350 km/h.

Moving the transport from the ground to the second level will free up the farmland with the area equal to the area of six countries like Belarus [20]. This land being occupied consequently with the green plants will allow to produce oxygen and remove about 1 ton of CO_2 per hectare daily, as shown in [27].

The construction of a slender overpass-type track located above the ground at the second level is characterised by the reduced material consumption and, accordingly, low associated cost and low consumption of mineral resources, such as steel and steelwork, non-ferrous metals, reinforced concrete, concrete, crushed stone, sand, and soil.

In comparison with the known types of roads built above the ground in the form of overpasses (high-speed railways and magnetic levitation trains), the savings of basic construction and structural materials will reach up to 250 bln tons of steel and rolled steel and about 3 tln tons of reinforced concrete when creating TransNet world network with a length of 25 mln km [20]. Such efficien use of resources will prevent the extraction, relocation, and processing of more than 3 tln tons of various

exhaustible minerals. In this scenario, overburdening operations with transportation of about 20 tln tons of the ground and fertile soils to the dumping site for many kilometres will not be necessary. Additionally, subsequent reclamations will be avoided to the non-allocated territories.

As a result of saving resources (even if imaginary, not real), about a trillion tons of environmentally hazardous and carcinogenic substances will not be transformed into solid and gaseous wastes.

While building TransNet network, the volume of earthworks will be reduced by more than 100 times in comparison with the process of laying the same length of the roads in a linear roadbed. Consequently, the natural landscape and biogeocenosis will not be significantly damaged and land reclamation will not be required in the construction zones and ground and sand mines. This is especially important when passing the route on permafrost and weak soils that are not able to withstand the additional load from the weight of the roadbed and additional temperature loads in summer created by such constructions.

There will be no embarkments and dugouts, sometimes reaching a height of 10 m or more, as for the modern roads and railways. Roads and railways disrupt the migration of domestic and wild animals, depress natural biodiversity, and hinder the movement

of agricultural and other equipment. There will be no swampy or deserted territories along these roads, especially on rough terrains, since each roadbed is a low-pressure earth dam that interferes with the movement of surface and groundwater (the soil in it should be compacted by 10 % compared to the natural occurrence).

This technology will save about 100 mln people from death in car accidents in the 21st century, and about a billion people will be saved from injuries and traumas, while string roads will not kill trillions of large and small animals that do not trap under the wheels of the “second level” transport. Land users of the planet will get back more than a million square kilometres of land, today “rolled up in asphalt” and “buried under sleepers”, and significantly larger areas of soil will not continue to degrade due to the proximity to motor-roads and railways.

The UST rolling stock is characterised by unprecedented efficien . So, in comparison to the Tesla electric car with pneumatic tires, the efficienc of the UST electric cars on steel wheels is 5–7 times higher. This indicator is also due to the absence of an airfoil effect because string tracks do not have a solid roadbed and traffic is carried out on thin string rails. This aspect alone improves the aerodynamic drag of the UST rail electric vehicles by 2–2.5 times [20].

The described advantages are especially noticeable for large-scale transportation systems – it is assumed that about 10 mln high-speed unibuses will run on the routes of linear cities (for comparison, the world’s car fleet today is about 1 bln) with an average capacity of 40 passengers (from 3–5 passengers for family cars to 150–250 passengers for trains made up of unibuses). Steel wheels, unique aerodynamics, and the absence of an airfoil effect reduce the power of resistance to movement at a speed of 500 km/h by 2,500 kW [20], which will save up to 25 bln kW for the mentioned unibus fl et. With a unibus utilisation rate of 0.75 (18 h/day), these parameters will save annually about 40 bln tons of fuel worth about 40 tln USD. Approximately 120 bln tons of oxygen will not be burned out of the planet’s atmosphere every year (including that in thermal power plants that generate energy for electric transport); almost 200 bln tons of exhaust and flue gases will not be released into the atmosphere.

Overall, in the 21st century the resource savings from the proposed global transportation string-based system can be summarised as:

- steel – 250 bln tons;
- reinforced concrete – 3 tln tons;
- exhaustible mineral raw materials – more than 3 tln tons;
- soil (including fertile soil) – 1 tln tons;
- fuel – 40 bln tons annually;
- atmospheric oxygen – 120 bln tons annually;
- environmental resource – the absence of annual emissions into the biosphere of about 400 bln tons of solid and gaseous technogenic wastes, including exhaust and flue gases

The cost of saved resources can be estimated as about 1,000 tln USD. The similar value will be saved in human and animal resources during the 21st century

and in additionally non-utilised 1 mln km^2 of land. It is also important that the planet’s biosphere will not contain 400 bln tons of fuel combustion products and technogenic pollution.

The existing global road network (more than 65 mln km in length) will be replaced by 25 mln km of string routes connected to the global TransNet network, which will pass through linear cities. At the same time, string transport will not require the construction of new highways in the future, since it will be able to serve the world’s population of up to 25 bln people (at the rate of 1,000 people per kilometre of the length of rail-string roads, or 1 person/m).

By the time the world’s transport and communication network of the new generation is completed, about 10 bln people will be living on the planet. At the same time, a network of linear cities with a total length of about 10 mln km will cover an area of about 10 mln km^2, or 1/15 of the Earth’s land area. This means that 14/15 of the land, as well as all the oceans and seas, can be provided for the national parks and nature reservation zones.

In the Soviet Union, the food problem was solved by allocating six hundred square metres per family of citizens, or about two hundred square metres (200 m^2) per person, which contributed to providing basic food supplies. As a rule, the allocated land was sparsely fertile, but due to the efforts of summer residents for 10 years, it turned into a highly productive area, with gardens and green yards. The linear cities of the system will provide five times more land per person – 1,000 m^2. Moreover, infrastructure (buildings, structures, residential buildings, etc.), as well as string routes, in principle, will not take away significant special resources from nature. On the contrary, new structures will help to get more crops – the barren land from under the foundations will be transferred to the fl t roofs of the buildings within linear citied and it will be enriched with humus. This combination will be used to create urban gardens, including multi-level ones.

A similar green experiment has been successfully carried out for five years in the EcoTechnoPark and Unitsky's Farm Enterprise in Maryina Gorka, Belarus. There are already six types of such buildings in operation, including those with a subtropical greenhouse and an indoor garden. The garden is arranged on the principle of a natural ecosystem – all effluent in the house (including from the kitchen and toilets) go to the root system of the plants, where they are processed into two products: fertile humus and industrial water, which is enriched with liquid humus, with the use of specially selected natural communities of microflora and microfauna (several thousand species). This experiment proved the hypothesis: man can feed not only himself, but also another individual with his biowaste, without poisoning the living nature, but enriching it with live fertile humus.

Linear cities will be made in the form of single-storey and low-rise clusters with areas of about 100–500 ha each. They are designed to accommodate 1,000–5,000 residents. They are located within walking distance around high-rise dominant terminals and stations, combined with shopping centres, hotels, and other public institutions. Industrial, sports and entertainment, shopping, educational, scientific, and other clusters will be located nearby, with the limited presence of the transport and the dominant roles of bicycles. Clusters can exist independently, since all necessary resources – water, heat and electricity, food – will be produced internally, within the cluster.

Residential and industrial buildings will be built using frame type structures with vacuum glass panels. An external vacuum panel with a thickness of 20 mm (know-how by the author of this study) is equivalent in its thermal insulation properties to a brick wall with a thickness of 1.5 m, which will result in savings on heating in winter and air conditioning in summer. The main raw material in construction is sand. There is a sufficien amount of it available on the planet for trillions of such houses. Glass walls of buildings are planned to be combined

with the photovoltaic panels or, if necessary, made in the form of screens that attribute to such houses an original external and internal appearance (a chameleon can envy such opportunities).

In addition to solar power, each cluster will include a power plant (for all-day energy supply for the transport and infrastructure) that will operate on brown coal and shale (and the waste from such a power plant will participate in the process of obtaining organic food). Available resources of brown coal will be able to supply such systems for at least 1,000 years, and the available shale resources will provide additional 10,000 years of operation. In much less time during the 21st century, thanks to the efforts of *Homo sapiens* (more precisely, *Homo engineers*), deserts and barren lands will disappear from the planet, since it is possible to recreate fertile land like black soil in their place and ensure the widespread appearance of forests and gardens, meadows, and fields

All wastes from the coal burning process (including fl e gases, sludge, slag, ash, etc.) will be mixed with the coal that has not participated in the combustion, and with the help of specially selected communities of microorganisms, the mixture will be converted into insoluble compounds, primarily – in insoluble salts of humic acids, i.e., in relic humus. Coal is a plant that lived about 100 mln years ago. It had received everything necessary for its growth and development (more than 70 chemical elements) from the ancient soil. All these minerals in the form of organic compounds, mainly humic acid salts (i.e., humus), will be returned to the soil in the developed process in the 21st century.

For example, sulphur is one of the harmful products of the coal combustion process, in terms of the impact on the natural environment. Green environmentalists

are now pushing for the widespread closure of coal-fired power plants, including the reason of the acid rain creation due to their operation. However, sulphur is needed as a macronutrient (each of us has more than 100 g of it). It should be consumed from the soil with food, which is proposed to be implemented in fundamentally new relict solar bioenergetics, which will use the mineral wealth of ancient humus and the energy of the ancient sun accumulated by plants during the Mesozoic and Cenozoic.

This means that such a power plant forms its wastes in the form of fertile humus. There can be applied 1 % of this product to any soil, for example, to the desert sand, in order to plant farm products. Such an experiment is currently taking place in the Unitsky's Farm Enterprise.

Excessive carbon dioxide from the relict solar power plants will be sent to the greenhouses (in cold regions of the world) or orangeries (in tropical regions). This will increase their productivity by several times. Heat, which is about 50 % of the energy of coal combustion, will be used for the specific needs of a cluster within linear cities, as well as for heating greenhouses in cold climates or air conditioning of the orangeries in hot countries. The nighttime excessive electricity will be used for additional lighting of greenhouses and orangeries, which will also increase their productivity.

The entire land area of Earth can be made fertile by natural, not technogenic methods without the use of chemical fertilisers and pesticides. It will require hundreds of billions of tons of humus and about 50 years to refine non-fertile territories (this time is still shorter than the period that it took the technogenic humanity to pollute and devastate the native planet). This will create another large business – saving

the Earth's biosphere. It is supported by the fact, that nowadays a ton of living humus in the market costs more than a ton of oil.

It is also possible to make Antarctica green. It is much more efficien and productive to develop it than, for example, extremely distant, cold, and deserted Mars. It is about 50 degrees warmer on the ice continent; there is air that can be breathed without spacesuits and masks (and at the usual atmospheric pressure) and there is food (fish in the ocean). A ticket here will cost almost a million times less than to Mars, the flight will take several hours, not months, as well as the probability for a settler to fly alive and healthy to the destination will be orders of magnitude higher. Besides, the settler has a disproportionately better chance of reaching the sixth continent of Earth alive and well. Only in Antarctica, at the rate of 1,000 m^2 per inhabitant, the entire future humanity can be settled – more than 10 bln people.

It should be mentioned that initially people will settle not in area with unfavourable climate conditions, but in the regions with comfortable natural conditions, especially along the equator.

The average speed on long trips along a linear city will be 400–500 km/h. Therefore, within a comfortable 30-minute time period, it will be possible to travel for 200–250 km. At this distance, there may be a located workplace, recreation, or entertainment for residents of a city embedded in nature. It will reduce the appearance of the existing megacities to the people and, it is expected, to reduce their population gradually.

The 40,000 km long Equatorial Linear City will become the backbone of TransNet network. The largest portion of it will go across the oceans [28]. About 100 mln people – 1 % of the world's population – will live and work there. Along the ELC, at a safe distance, there will be a take-off and landing overpass of the General Planetary Vehicle – the vital link between the Earth civilization and the growing space industry.

In outer space. The entire terrestrial industry currently exists in the Earth-based technological environment, which is based on the specifi gravity value (gravitational acceleration is 9.81 m/s^2) and an air gaseous and chemical environment under the pressure of 760 mm Hg, containing 21 % of very active oxidizing agent – oxygen. For this reason, gravity does not allow the creation of alloys and composites from materials with different densities – they are getting delaminated by the gravity forces. Many technological operations cannot be performed in the air, so they require vacuum systems. Moreover, obtaining a cubic metre of deep vacuum in terrestrial conditions is currently more expensive than extracting a ton of oil.

When the molten steel is poured out of the blast furnace, it burns and smokes. Thus, the process of metal oxidation with air oxygen takes place, as a result of which the metal loses its qualities [29, 30].

When obtaining medicines and, in particular, other highly-purified substances without impurities, ideal conditions are required, so the workshops for their production have a multi-circuit air purification system. However, this does not always help – even the most sterile air contains millions of tiny dust particles and thousands of microorganisms. Earth solar power generation industry does not work at night,

in rain and cloudy weather, and the surface of solar panels should be constantly cleaned of dust and dirt.

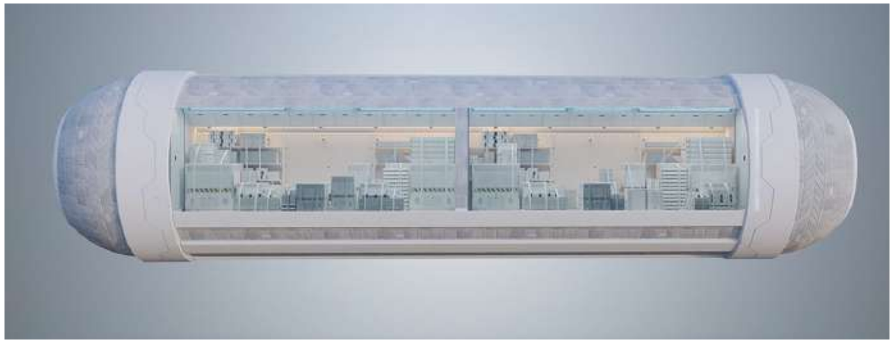
We can continue to list the disadvantages of the planetary technological environment – there are thousands of them, including the limited material and spatial, as well as energy and information resources.

The cosmic technological environment has many advantages. Weightlessness is the first one. If gravity is needed, it can be artificially created. The second advantage is deep vacuum and ultra-purity (including the absence of gases, air, and microorganisms) extending to infinit . Thirdly, solar power plants (slender, light, because they are weightless) in high orbits will work around the clock and year-round, they do not need to be cleaned of dust and dirt.

The geospace cargo flow itself will determine the pace of development of the space industry for the benefit of our civilization, living in historical house – in the biosphere of planet Earth. At the same time, in the future, the annual individual consumption of industrial products should be commensurate with the ergonomics of a person, and above all, with his or her body weight. So, for 10 bln people – this is at least 100 mln tons per year of space products or at least 10 kg per resident of the planet.

Thus, the main criterion of the space industry is the number of products produced in space and delivered to the Earth's surface to its customers. Geocosmic transport has to play a key role in this process.

Design principles of geocosmic transport are fundamentally different from the approaches, used in the design of land vehicles.



The fact is that we are on a planet in a very deep gravitational pit, out of which we can either climb to infinity or fly out of it with the first cosmic velocity, equal to 7,919 m/s at the zero altitudes. And not vertically up, but passing over to a low circular orbit, i.e., parallel to the surface of the planet. Therefore, each ton of cargo delivered to orbit must be supplied with a minimum of 8,700 kWh of energy, which, for example, corresponds to the kinetic energy of a train about 20 km long and weighing more than 80,000 tons, rushing at a speed of 100 km/h (the rocket system spends ten times more energy on this work due to the low overall efficienc factor of the system). The traditional ground transport does not need so much energy – it moves from

point A to point B horizontally along the bottom of the "pit", that is over the surface of the planet.

Extremely high energy expenditures during the industrialization of space impose a number of serious restrictions on geocosmic transport:

- its efficienc factor should be close to 100 %, since even a relatively small release of energy into the environment, i.e., into the atmosphere through which cargo should be transported to orbit, will lead to catastrophic environmental problems during the operation of geocosmic transport;
- it is necessary to use the most environmentally friendly energy – electric – as the reference energy for geocosmic transport.

In addition to solving environmental problems, an increase in the efficiency of geocosmic transport will reduce the net cost of delivering cargo to orbit, which is inversely proportional to the efficienc of the transportation system (similar to any ground mode of transport).

The proposed concept of the GPV meets the main requirements and needs of the geocosmic transport in large-scale space exploration [1, 5, 20, 22, 31].

In the first years of the GPV operation (presumably 2040–2045), about 100 mln tons of equipment, structures, and materials will be delivered to the near space from the Earth, sufficien to create the following elements within the equatorial orbits at an altitude of 300–500 km [20]:

- solar power plant with a peak capacity of approximately 2 bln kW (this is the capacity of all power plants in the world today), since about a kilowatt of power can be obtained from 1 m^2 of the surface illuminated in space. Fuel for these and subsequently built power plants – from hydrogen in our Sun – will be sufficie for at least 5 bln years;
- several hundred EcoCosmoHouses (ECH) for long-term residence and work conditions on the orbit for several hundred thousand people [32];
- the basic linear platform of Industrial Space Necklace "Orbit" (ISN "Orbit") with the relevant infrastructure communication (transport, energy, and information) along it, made using string technologies, with a length of more than 42,000 km.

ISN "Orbit" will be a transport, infrastructure, industrial and residential complex that encircles the planet in the equator plane at an altitude of several hundred kilometres. Externally, the space complex will look like a necklace of cargo and passenger modules delivered to the orbit, being spaced at about 500 m, connected by "threads" – string orbital roads, as well as energy and information communications.

Around space string communications and infrastructure modules, as catalysts, "crystals" of the orbital industrial ring will grow up over time – laboratories, shops, factories, power plants, and other industrial facilities. The personnel servicing the space industry will be able to live and work in the residential biosphere settlements built nearby with more comfortable conditions than on the planet.

Eventually, the population will reach about 10 mln people (0.1 % of the Earth's population).

During the 21st century, the main part of the Earth industry will be removed from the planet to be further recreated in the near space on circular equatorial orbits in space technological environment. To implement this plan, 5 tln USD of investment annually will be sufficient which is half of what is currently planned to be invested in the resource revolution and the salvation of the world economy. This will allow within about 50 years to complete reloading of our technogenic civilization to the space vector of development according to a new resource logic under the motto: "The planet is for life. Space is for industry". Moreover, the GPV will be almost the cheapest part of this reloading with the initial cost around just only 2.5 tln USD for construction [20].

An anthropogenic biota will be created on 1/15 of land (or 1/60 of the planet's surface). It will be able to feed and service humanity and the natural biota will be preserved on the rest of the land (14/15 of land or 59/60 of the entire surface of the planet). This will ensure the natural biological regulation of the environment that existed in the pre-industrial era. The main part of the technosphere will be located in the outer space, while the remaining terrestrial industries will include agriculture, medical, earth environmentally friendly transport and infrastructures, environmentally friendly constructions and pedestrian linear cities, as well as individual, environmentally friendly structural elements of the general planetary energy generation engineering, communications, and mechanical engineering.

Transfer of the industry into space will open up access to inexhaustible mineral resources in the Solar System, in particular, to heavy metals that have very limited presence on Earth. For example, the asteroid Psyche, located in the asteroid ring of the Solar System between Mars and Jupiter, with a diameter of 250 km and a mass of about 10^{18} tons, by 90 % consists of iron and nickel [33].

The Industrial Space Necklace of the planet will become a fundamental element of the protection system from space threats (including meteorites) and a platform for expansion into deep space. Within the ECHs, it is planned to create various biosphere banks delivered from the Earth: living fertile soils, microflora and microfauna, flora and fauna. Consequently, no man-made or natural disasters on the planet that can kill the Earth's biosphere will be able to destroy thousands of closed and autonomous ecosystems located in orbit.

The Earth technogenic civilization, taught by the bitter experience of difficult relations with the surrounding nature on its home planet, in its home – in the living biosphere, will take careful steps in space in order to also harmoniously fit into the surrounding space environment – in an alien (already cosmic) home, although dead in the vicinity of our planet.

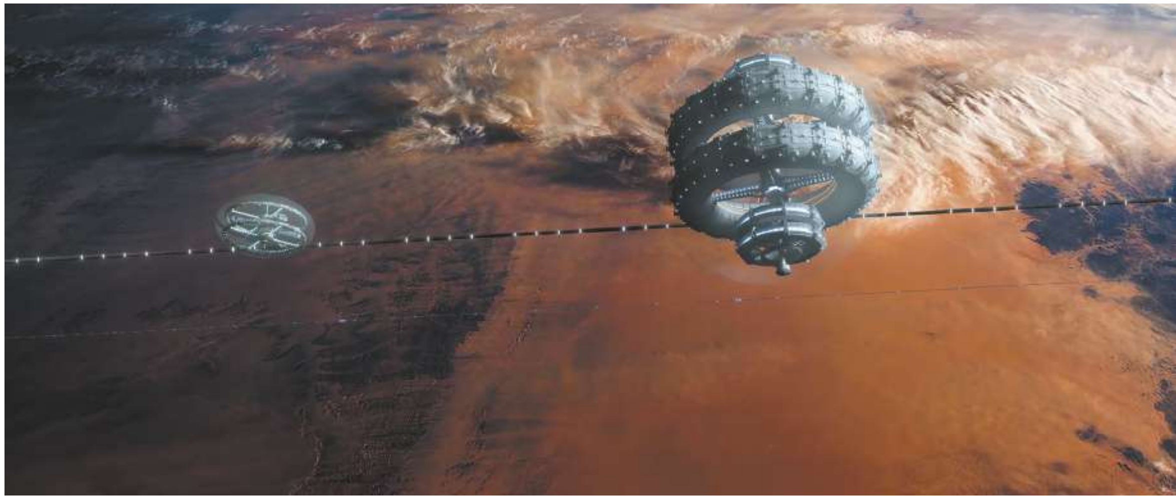
The author of this study has little influence on the choice and implementation of one of the described scenarios for the development of humanity, which is currently at the point of a technogenic civilizational fork – to live in a "biospheric Petri dish", trying to extend its comfortable existence in all possible and not always thoughtful and humane ways, or to open a technological exit into space for our Earth's technocracy.

We still have time to make a choice, but in 15–20 years it will be too late, because fateful decisions for us, earthlings, are made chaotically and haphazardly by the so-called "world elite", spontaneously assembled from politicians, bankers, and owners of the largest fortunes. At the same time, there is not a single engineer among them who is able to think comprehensively and systematically on a global scale. This means that they will lead our civilization "into a bright future" according to scenario No. 1 described above – to a place where here and now you can get fabulously high profits from global problems of humanit .

And yet the biosphere does not have a pre-prepared "secret door" through which someone, including the world's elite, can go out and hide – neither a private island in the ocean, nor a deep bunker in the mountains, nor a Boeing with counter missile defense can perform such a role. Everyone, without exception, is forced to follow the same biosphere path and go the same way that all of humanity has turned to – today's story with the coronavirus pandemic confirms this. Going in the direction of its inevitable degradation, extinction, and death, and by historical standards, not in the long term, but the foreseeable future.

In fact, the choice of ways of development depends little on humanity itself, which does not have a single governing body. Only local decision making centres are organised – governments of individual countries, primarily industrially developed ones, which are essentially not much different from the tribal leaders who once lived in their separate caves. At the same time, they can be persuaded to sit down at a common negotiating table in order to jointly choose the only right path to a sustainable future for the biosphere of our planet and for humanity, described in scenario No. 2 of the technosphere reloading.

In its transformative essence, reloading of the technosphere, described from an engineering point of view, is summarised in the EcoSpace programme (an environmentally friendly world) as the possible way to save our civilization.



4 Conclusions and Future Work

In order to survive, humans for the second time in the history of their existence must remove industrial technology outside the home: for the first time – outside the Earth's cave, and for the second time – outside the Earth's biosphere. This will enable our man-made civilization not only to survive but also to develop steadily and infinitely in time and space of the limitless Universe

The proposed EcoSpace programme can become a global asset and a tool to achieve all 17 goals of the sustainable development of the Earth civilization, proclaimed by the United Nations. Furthermore, this programme leads to the creation of an improved world that includes the Earth's BioSpace, cosmic TechnoSpace and HomoSpace to unite them. It is necessary to focus on the three areas of the EcoSpace in the further research, although, cosmic TechnoSpace as "engineering pillar" is most close and personal to the author as an engineer.

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1 Modern Challenges of Industrial Development and Space-Directed Ways to Solve Them

1.1 Introduction

Modern technocratic civilization has built its foundation on the unsustainable platform of the hazardous industries. Such approach led to the significant damage to the biosphere of the Earth. The chapter discusses the historical retrospective of the key problems of changes in the Earth biosphere because of the existence of a technocratic civilization. The author focuses on the low sustainability of the rocket-based space exploration methods from ecological and financial perspectives. Chapter justifies the only possible solution to the raised issues, which is removal of the hazardous industries beyond the biosphere using innovative geocosmic transport. Developed solution is based on environmentally friendly and efficient technologies.

1.2 Problems Analysis

About 14 mln living species are currently present on the Earth, based on the estimates [1]. The scientists know only 12.5 % of the existing species, which is 1.75 mln.

Every hour about three living species disappear from the Earth, which leads to the extinction of more than 70 species per day or 26,000 species per year [2]. The main reasons for the extinction are evolution or natural factors and anthropogenous factors. The disappearance of the species is irretrievable. Some of these species have unique structures and they were not created to be extinguished by someone.

Biological species are proved to have unimaginably complex structures. In includes not only entire living creature or their organs and cells, but also their DNA macromolecules. One DNA molecule, which transfer genetic information, is hundreds of thousands of times more sophisticated than the most complex engineering devices, like Boeing airplane. One human body contains about 100,000 genes in the DNA. Macromolecules contain huge variety of chemical elements from the periodic table, which are structured into complex, but reliable structure. This solution has high-proved reliability, tested by millions of years of evolution, and it is capable of self-reproduction.

Rapid growth of existing pollutants in the air, water, and soil has led to the increased number of cases of allergies, cancer, lung and cardiovascular diseases, as well as genetic disorders and hereditary human diseases. Furthermore, technocratic society has heavily impacted the landscape and soil structures. Deforestation is another negative result of the globalization and industrial development. Water resources contain the vast majority of the chemical pollution footprints form the factories and chemical industry. Finally, ozone layer depletion represents the most harmful for the living beings, in the future perspectives, result of the current activity of the humanity. Moreover, all these changes are irreversible.

Degradation of the environment is caused by various reasons. Understanding key contributing factors and acting upon, might result in the full avoidance of the degradation. Furthermore, smart utilisation of the findings will support determination of the sustainable development of techno civilization.

This chapter analyses the main causes of the biosphere degradation and the possible ways to apply positive impact on the future development of the system. One of the chapter sections analyses the initial historical development of the elements of the biosphere and initial presence of the human-made technical systems within it. Another section covers the key challenges of the technocratic society and its footprint. Finally, the concept of space industrialization is presented, as the possible solution to the presented issues. At the same time the canvas, paints, and brushes are prepared in advance. In moments of inspiration, there is no time to think about brushes and canvas – you have to create art.

1.3 Historical Development of Biosphere

Recent researches have shown that the life was created on the Earth about 4 bln years ago. Two processes happened back then – living organisms were adapting to then existing conditions and the organisms transformed environment. These transformations were of similar significance to the system's functions. As a result, the oxygen-containing atmosphere appeared on the planet, which had been initially deserted. Furthermore, the nowadays-common biological systems were created, such as soil, coral islands, savannas, forests, swamps, tundra, jungles, etc. Finally, the biosphere was formed. It combines millions of species of living organisms and the planet, which was transformed by them over billions of years. These parts are ideally "fitt d" to each other through the evolution process. In addition, there is nothing superfluous presented in this combination

Special focus should be attracted to the fact that the entire biosphere of the Blue Planet was created based on the living organisms' wastes. Photosynthetic bacteria and green plants develop oxygen and ozone. Fertile soil and humus are the wastes of the dead plants and creatures, which were also passed through the digestive systems of the other organisms, including microorganisms and insects.

In the further process, the humankind has been created. To sustain its presence in the environment, the senses of accuracy and strength of the bodies of the humans were evolved and strengthened. Furthermore, intelligence of the human's mind initiated creation and development processes of the technologies. These processes happened hundreds of thousands of years ago with the primitive people. In the beginning, they began to manufacture the first production tools. Second, they stated cooking food on the fireplaces. Third, animal skins were processed to improve their living spaces – the caves. Due to the presence of the smoke in the living areas, cave people used to die from the lung cancer in their 20s. However, human species survived the early-deaths by translating technologies from their direct living areas to the environment – the biosphere. As a conclusion, the planet's biosphere has become a home for the nascent humanity civilization.

Evolution pushed humanity to follow technological-based development, which cannot be changed nowadays. Logically, this way evolved in the modern industrial power of the Earth's civilization. *Homo sapiens* have united into the local societies, and later, with the emergence of the industry, into a planetary civilization, which has now become qualitatively different form of life – *Homo technocraticus*. The term "technocratic man" (in Latin *Homo technocraticus*) was used to describe the way of thinking in the common sense, such as "mercantile man". Initially, "mercantile" meant "commercial", and the expression "mercantile person" meant a "good businessman". The "technocratic man" was supposed to be the next stage in the qualitative development of *Homo sapiens*, but technocratic tyranny shows the opposite result – regression of the species.

In the 21st century the term *Homo technocraticus* was actually narrowed down to the concept of the "inhabitant of the asphalt jungles", since most people have begun to live in the agglomerates. Nowadays, asphalt is covering a huge portion of the planet with the total area equal to the combined area of five Great Britains and total length exceeding 30 mln km. This area carries dead soil. It does not grow green plants to produce oxygen necessary for the human breathing. Furthermore, soils adjacent to the roads and having 10 times larger area are degraded and polluted with the carcinogens from exhaust fumes, rubber tire wear particles, and asphalt products. In addition, about 1.5 mln people are annually killed on the roads with much higher numbers getting crippled and disabled [3, 4]. It makes traffi accidents the eighth leading cause of death worldwide and, most importantly, the main cause of deaths for children aged 5–14 years and young people aged 15–29 years. Furthermore, there are billions of domestic and wild animals killed in the road accidents, yet no reliable statistics available.

Road vehicles burn more than 2.2 bln tons of the fossil fuels annually, passing more than 35 bln tons of life-giving air through the high-temperature combustion, which leads to the burning of more than 7 bln tons of oxygen out of the atmosphere [5]. This amount of oxygen can be produced in a year time by the pine forest covering an area of 240 mln ha.

1.4 Analysis of Footprint of Technosphere

An analogy can be drawn between the combination of the factories, power stations, machine tools, automobiles, and other engineering devices of the technosphere created by techno human and living organisms in the biosphere [6]. Similar to the living organisms, human-made systems exchange energy, information and matter with the environment. Therefore, like living beings, they should inevitably transform their surroundings.

Technical systems use raw materials, as inputs, and finished products or services as outputs, for example, energy, information or transport. Converted materials, excluding the finished products, are being contributed back to their origin – environment – in form of a waste. It is impossible to avoid such flo . Furthermore, it is also impossible to create enclosed, “green” engineering technological cycles, which become the dream of those environmentalists and their first solution. The approach is similar to the attempt to ban production of wastes by cattle, such as urine, manure, methane, and CO_2, alongside with the required production in the form of meat and milk.

Even the entire biosphere cannot be seen as an enclosed system. It is an open system, which supported transformation of the before dead planet. On the larger scale, the only closed system can be seen as the Earth – Biosphere combination. For further accuracy, this system is not fully enclosed, as it absorbs the energy of the Sun, cosmic radiation, cosmic dust, and meteoritic matter, and it radiates technogenic light at night and electromagnetic radio emissions 24 hours a day.

Elements of the technosphere do not need an oxygen-containing atmosphere, as they can adopt alternative channels of energy and sources of chemical elements. As an example, American oxygen consumption can be analysed. Nowadays, industrial sector in the USA, including transport, consumes more oxygen, then the rate it can be produced by green plants on the area of the country. As a result, American citizens live indebted. They consume oxygen produced by other countries, for example, the Russian taiga and the Amazon rainforests.

Another resource, which is not important for the technosphere, is the fertile soil. Therefore, the fertile land size decreases and the number of dumps, slags, ashes increase. Hence, the planet has less and less fertile lands, and more and more dumps,

slag, ash, and terricones. At the same time, healthy fertile soil, such as chernozem, might contain in a kilogram about a trillion microorganisms of several thousands of various species, which makes it an immune system of the entire biosphere. Each type of the soil-based microorganisms has their own, even more narrow, specialization, as compared to human-developed professions, such as driver, plumber, driver, etc. These species create universal nutrition for plants – humus, all sorts of insoluble humic acids and salts. With the absence of the microorganisms, rainwater would wash out all nutrition elements from the soil.

Soil is the substance where the food chain starts for the majority of living organisms and most viral diseases, including the deadliest ones, end.

Some types of microorganisms enable access to the stored nutrients – organic compounds, which contain the entire set of chemical elements necessary for life (about 80 from the periodic table) in the form of thousands of specific and complex organic compounds (and not simple chemical compounds, such as chemical fertilisers), i.e., the humus is converted into a soluble form and thus the plants are fed.

Despite these advantages, humans started to kill the soil microfl ra and microfauna, which is the immune system of the biosphere, by plowing it, adding mineral fertilisers, herbicides, and pesticides, creating asphalt roads and spoiled tips. It will lead to the transformation of the biosphere of the Earth to the model of an AIDS patient with a weakened immune system who can die from previously harmless disease.

Impact of the industrial presence can be seen in the increased number of acid rains, smog density, increased levels of radiation, destruction of the ozone layer of the planet, etc. The only possible solution is to slow down the transformation process of the Earth’s nature and the biosphere, as it cannot be stopped. The technosphere occupies the same ecological niche as the biosphere itself: machines, transport vehicles, mechanisms, technical devices are located and they are actively interacting with the midst of the earth, water, and air.

Environmental problems have recently become aggravated only because the power supply capacity of the technosphere (i.e., its capacity to transform the environment) has approximated that of the biosphere. For example, in the process of photosynthesis, the biosphere now reproduces about 150 bln tons of dry organic matter per year [7], which, in terms of the fuels, is only by an order of magnitude more than the annual energy consumption of the all machinery used by the civilization. In addition, the volumes of soil, coal, ore, and other types of raw materials transported and processed by various equipment are already very close to the volume of production of the organic matter in the biosphere.

From a biological point of view, the humankind, as a species of living beings, is a “child”, for whom the biosphere is a “parent”, which was given an inheritance of 500 mln tons of biomasses (about 350 mln tons of which are water). As a result, humankind does not pose any danger to the biosphere as a total mass of living matter in the biosphere is about 2.5 tln tons (of which about 1.8 tln tons are water) and the mass of the humanity is less than 0.02 % of it. Therefore, metabolism and homeostasis of civilization as a community of people, as an open biological system, are less significant for the planet's biosphere than a random colony of the microorganisms that has a larger total mass.

Global problems are actually created by the homeostasis of a completely different "child" – the one that was created by the *Homo technocraticus*. This "child" is called – the industry. It has a rapid growth, its appetite is steadily increasing, and its mass, which is useless in many respects, approaches the mass of living matter on the planet.

Recently another culprit of global warming has been discovered – bitcoin. The cost of electricity to maintain a non-optimal bitcoin payment system already accounts for about 1 % of the total world energy consumption. One transaction requires as much energy as an average family spends per month in the Netherlands. If the growth rate remains and the essence of this non-optimal information technology does not change, then in the short-term perspective, mining will consume up to 100 % of the total global electricity production [8].

Thus, not only material substances associated with the processing, but also information technologies are causing increasingly tangible environmental damage. Although the information itself is not material, it is stored and processed on tangible media, which creates further environmental problems.

There is only one cardinal way out of the current situation: it is necessary to provide the technosphere with an ecological niche outside of the biosphere. This will ensure the preservation and development of the biosphere according to the laws and directions that have been formed during billions of years of evolution, as well as this will ensure harmonic interaction of the community, as biological objects, with the biosphere.

1.5 Concept of Space Industrialization

The place for the technosphere does not exist on the Earth, but there is a niche in the near space, at a distance of 300–500 km from the surface of the planet. It provides ideal conditions for most technological processes: weightlessness, vacuum, ultrahigh and cryogenic temperatures, unlimited raw materials, energy and spatial resources, etc.

The conclusion is as following: it is necessary to industrialize the outer space environment in the future, if the Earth civilization will continue following the technological way of development. Technocratic oppression of the biosphere leads to the irreversible degradation of all elements of the system, including the humanity. In order to slow down the degradation processes, the time to apply changes is limited to the two human generations, according to various predictions and models. This will be the point of no return for the technocratic civilization of the Earth with no possibilities to turn changes back.

The humankind has no experience in the near-Earth space industrialization at the present moment. There is a set of issues to be addressed. What should be the space industry? What are its functions? What are the volumes and what types of goods should be produced there? Where will these products be mainly consumed: in the space or on the Earth? There are no clear answers today to the mentioned issues. Nowadays, any prediction can be correct or faulty. The answers will depend on the development approaches applied to the mass space exploration.

The firs industry to be removed from the biosphere to the outer space should be the goods manufacturing due its high environmental footprint, exhaustion of the raw materials, high-energy consumption, and high temperature loading. These artificially made goods do not fit within the biosphere with the biological species, formed during 4 bln years of evolution within the Earth conditions.

We are ideally adjusted to the gravitational, magnetic, and fi lds of the Earth, to the chemical composition of the air, which is saturated with phytoncides of plant's blossoms, to the Earth's spring water, which contains required microelements for the human being, to the foods grown on the Earth's fertile soils, and much more Earth's-based things we are not even aware of. Without such systems, we can exist not today, nor in the foreseeable future. There is no place in the vast universe for us, people of the Earth, with more suitable living conditions than on our beautiful Blue Planet. Therefore, the main consumers of the products from the future space industry, and this is about 10 bln people, will be on the Earth.

Space industrialization will lead to the creation of conditions for production of various goods, energy generation, machines manufacturing, obtaining new information, implementation of technological processes and scientific experiments on the orbit. Consequently, significan cargo traffi is inevitable between the consumers of the goods – humans living on the planet – and the production areas on the Earth orbit. Therefore, the manufacturing should be placed as close as possible to the consumers in order to improve the geocosmic logistics.

Since human beings have consuming behaviour, people's consumption of products, both supporting life (food, water, air, etc.), and industrial needs (telephone, computer, refrigerator, TV, car, etc.) is related to his anthropometric characteristic: size (average height of a person is 1.65 m) and body weight (average 62 kg). Therefore, the annual per capita consumption of industrial products in the future should be commensurate with the mass of a man. For 10 bln of people, this figure will be at least 100 mln tons per year, or 10 kg per individual.

Geocosmic transport is the main bottleneck of the presented space industrialization and the pathway to make the Earth civilization a truly cosmic one. According to the most ambitious forecasts, the well-known geocosmic transport systems, such as launch vehicles, space elevator, electromagnetic gun, etc., are capable of transporting only a few thousand tons of cargo per year along the Earth – Orbit – Earth route, which is tens of thousand times less than required. It means that current transportation capacity is less than 1 g per each inhabitant of the planet per year.

If we were, for example, a civilization of micro-Lilliputians with weight of about 1 g, then such volume of transportation would suit us perfectly. However, for the current civilization this is no sufficien number. If solutions to this problem will not be found in the near future, our Earth's technocratic civilization would suffer in the same way as the mold in a Petri dish: after having eaten all the limited resources and having poisoned the limited space with its wastes, it will die. It is only a matter of time, but it will happen, eventually.

1.6 Prerequisites for the Formation of the Idea of General Planetary Vehicle in the Philosophy of Russian Cosmism

Space takes a special place in the worldview of the Slavic people. The attitude to it in Slavic culture is different in comparison with both ancient and new European traditions. The space for the Slavs used to be interpreted as the sphere of moral and ethical choice and a corresponding act, performed by everyone individually and by the whole humankind. Civilization turns out to be responsible for the fate of the planet Earth and the safety of the life forms that inhabit it.

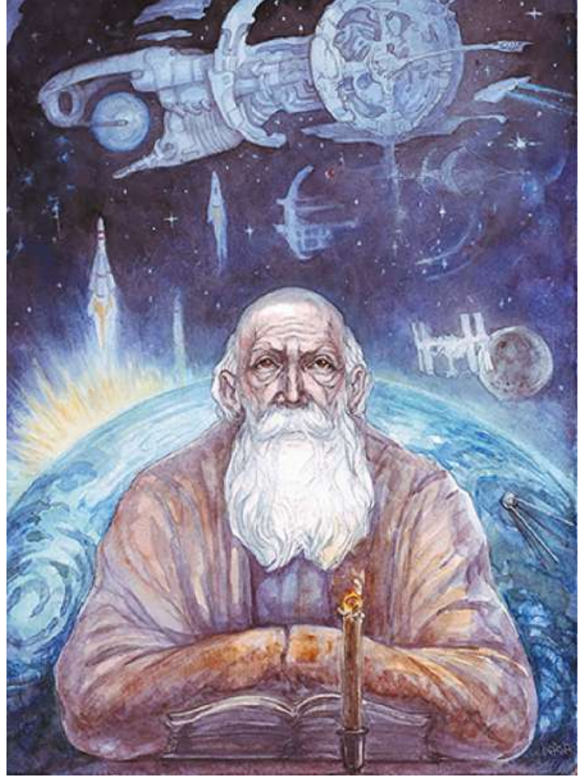
The special perception of the space was reflected in the philosophy of Russian cosmism, and then it was developed in the Soviet philosophy, thus being firmly included into the structures of national consciousness and self-determination of Russian and Soviet people. From different points of view, such disposition is caused by considerable achievements of the Slavic people in the fiel of astronautics.

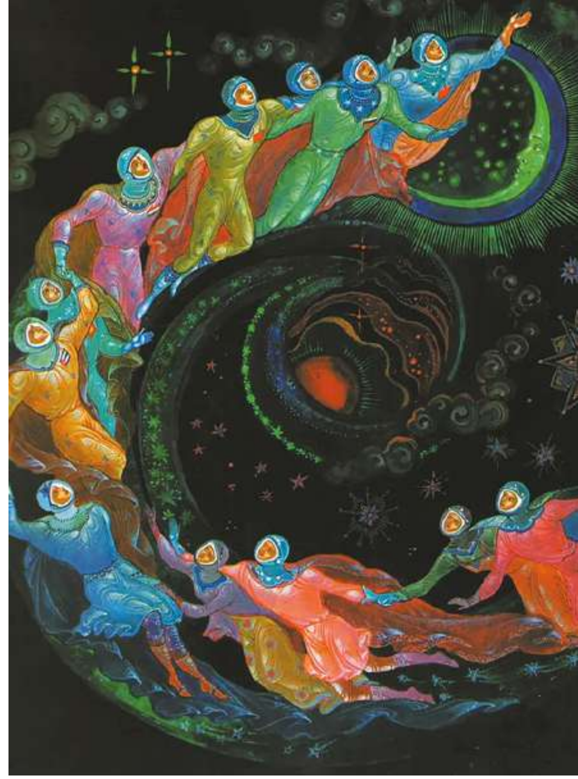
"Moral measurement of the space" being developed within the Russian philosophical tradition, it is again becoming a relevant topic with the growing presence of the global environmental problems that humanity is facing in the 20th – 21st centuries. In this regard, space exploration issues are no longer purely scientific or commercial in their nature, but they touch all the way down to the fundamental problems related to the survival of civilization.

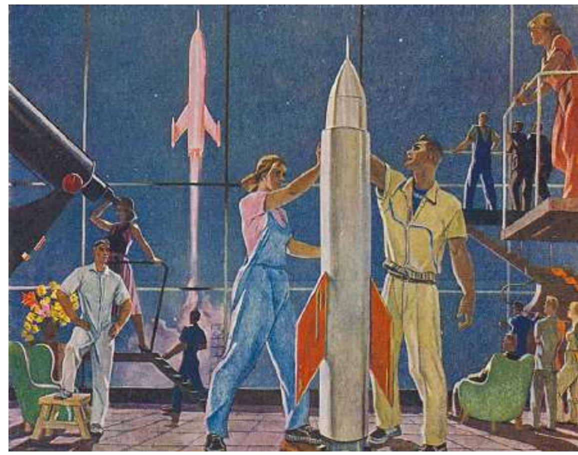
A. Review of the Works of N. Fyodorov, V. Vernadsky, and K. Tsiolkovsky

N. Fyodorov is considered as the founder of the space direction in Russian philosophy. At firs glance, his theories may seem naive. However, the vector of his thinking does not only remain relevant in today's world, but also encompasses the possibility of solving global problems faced by civilization in the 21st century.

N. Fyodorov's teaching is called the Philosophy of the Common Cause. The researcher initiated his theories from the original brotherhood and kinship of all people. However, the board of knowledge in his time and currently indicates the opposite truth – humankind is in a state of dissociation and non-fraternity. "Under the state of non-fraternity", was written by N. Fyodorov, "we understand all legal and economic relations, class and international discord" [9]. Both then and now it is an obstacle to the development, improvement of a society and each individual as its integral part. It is necessary to overcome spiritual, economic, political, and other types of discord in order to reach a new civilization level.







Immortality was proposed by N. Fyodorov as the ultimate goal for the humankind development. The philosopher based himself on its achievement in conquering nature. Science, which was chosen as a third party to reconcile the enemies, should instead act as a weapon in the battle. Philosopher described this process as follows: "Who is our common enemy, a single, everywhere and always inherent in us and living outside us, but nevertheless the only temporary enemy? This enemy is nature. It is a considerable force until we are powerless, until we become its will. This power is blind, we are unreasonable until we make up its mind... Nature, a temporary enemy, will be a friend forever, when in the hands of the sons of human it will turn from a blind, destructive force into a demiurgeous will force" [9].

The basic of our existence (and not nature that surrounds us) was identifie by N. Fyodorov as the reason for our non-fraternity. Our biological needs, fear of death, disease, and poverty leading to death, make us see each other as threats and figh for space, resources, and so on. On the other hand, death, as dictated by nature's inevitability – in reality, was named as the ultimatum uniting all people and the thing, which makes them equal one to another. Therefore, the main fight was identifie against the unific tion reason. This goal of civilization development will be seen by many people as utopia, something unattainable, but it is hard to disagree with the statement: "…in philosophical terms the question of immortality and even resurrection cannot at least be thrown away as reactionary or dark-occult one" [10].

In the fight against death is that "common cause" around which humankind should unite, once and for all ending all animosity, because all people in biological terms are related to each other, coming from a common prehistoric ancestor. Therefore, the same attitude that exists within the family with its common interests, goals, and objectives should be established among all people. The home of this family is not only the planet but the entire Galaxy, which we will have to explore if we live indefinitely having the growing population and limited terrestrial pace.

The main idea which can be subtracted from the N. Fyodorov's philosophy in the context of the cosmism formation is the hypothesis of world population unity to achieve common higher goals. It is important that these goals have practical application, because immortality, if we consider its possibility, as well as death, both have practical nature. Motion towards this high goal must inevitably be accompanied by improvement of life quality of people, who will become healthier and have increased lifetime until the times, when death will be pushed to some infinite perspectives. This wide horizon changes in the conditional state not only temporary determinants of human existence, but also spatial ones. Humankind, through scientific and technological progress, should strive to achieve eternity in infinit . The space, the Universe, being not a hut, a village, a city or even the planet, then will become our habitable environment and the sphere of responsibility for the intellectual activities. This meaning of N. Fyodorov's teachings was picked up and developed by other representatives of the cosmism, from whom we will highlight two researchers, whose teachings have been identifie having the most developed natural-scientific component therein

Although K. Tsiolkovsky is known as the founder of the rocket cosmonautics, he, by himself, considered space philosophy as the highest achievement.

"Tsiolkovsky's worldview concept is based on the principles of the unity of human being and the Universe, as well as on the projective attitude of the people to the world, which implies fundamental transformations of the Earth, space, and person himself with the support of his mind. 'Mind is the greatest force in space', the scientist never tired of repeating it" [11]. Space, according to the great inventor, is the unity of the mind and the matter, which is in the process of self-organisation and evolution. It was stated, that humanity is not the only carrier of the mind. The Universe is inhabited by many sentient beings, the mind is endowed with the Universe itself. Mind arises in the process of self-organisation, passing a number of stages from a physical vacuum, through the emergence of quarks, gluon plasma, atoms, protoclusters of galaxies, then the emergence of the galaxies themselves, stars, planets, biosphere, anthroposphere, sociosphere, and the actual sphere of mind, which in the works of Vernadsky was, called noosphere. According to K. Tsiolkovsky, the noosphere is the peak of self-organisation and it is a determining factor in the further development of the Universe. The most important stakeholders of this process within the terrestrial space are geniuses. "Geniuses have performed and are performing miracles!" [12]. Geniuses "are needed not only to spread and assimilate truths that have long been discovered, though not used by people, but also to obtain new ones. Moral and the entire light comes from geniuses" [12]. "The thoughts of geniuses are immortal, as well as their works, because even after death they continue and give infinite and unending benefi s" [12]. In order to increase the number of geniuses, it is necessary to increase the population of the planet, along with a defined selection process of human being as a species. More "perfect" people should give more descendants, less "perfect" people should refuse to continue the genus at all. For these ideas K. Tsiolkovsky is sometimes called a "space fascist".

The need for space exploration and industrialization is linked to the population growth aimed at increasing the number of geniuses. People will "manage the climate and will control it within the Solar System, as well as on Earth itself. They will also travel beyond the planetary system; other suns will be reached..." [13]. In this sense, we can understand the famous statement of the scientist, "The planet is the cradle of the mind, but you cannot live in a cradle forever" [14]. The technologies, which the humankind is going to use to explore the space, was the key interest of K. Tsiolkovsky. Besides rockets, he theoretically considered other options – a space elevator, a planetary train, etc. However, the missiles got the most elaboration in his works.

Mind, described by K. Tsiolkovsky as the greatest force in the space, is in the centre of V. Vernadsky's philosophical works. In general, Vernadsky belongs to the natural-scientific direction of Russian cosmism. Vernadsky agreed with Tsiolkovsky that human being and humanity cannot be regarded in isolation from the global processes and phenomena. First of all, according to the scientist, a human being is connected with "a living natural body" and "living matter" of the environment – the biosphere. At the same time, he defined "living matter" as the "totality of living organisms living in it" [15]. In turn, living matter is in constant intensive interaction with the non-living elements of the biosphere and outer space, with which they "have a continuous material and energy exchange of atoms caused by living matter... Planetary, cosmic value of living matter is manifested sharply in this biogenic current of atoms and in the energy associated with it. Since the biosphere is the only Earth's shell, it is continuously penetrated by cosmic energy, cosmic rays and, above all, the Sun's rays, thus maintaining a dynamic equilibrium and organisation: biosphere ↔ living matter" [15].

The biosphere, by converting activity of the minds, was identifi d as not only part of the terrestrial local processes, but also of the life of the entire Universe. "A human being creates in the biosphere a new biogenic force, directing its reproduction and creating favourable conditions for its settlement in the parts of the biosphere, where his life has not penetrated before and in some places even any life, by means of scientific thought, state-organised, directed by its technique, and own life. Theoretically there are no limits to his possibilities" [15], was written by V. Vernadsky. It stated that humankind on a planet scale has a controlling role, and its route into space is a natural and inevitable stage of evolution. However, this can happen under certain conditions associated by scientists with the formation of the noosphere.

"Two things, therefore, are prerequisites for the replacement of the anthroposphere by the noosphere: the domination of human being over external nature and the domination within the human beings themselves of the reasons being prevalent over lower instincts" [15]. At the same time, as in the works of other cosmists, scientifi and technical progress turns out to be a tool for achieving this goal: "…the course of history of scientific thoughts appears before us as a natural process in the history of the biosphere. The historical process – manifestation of the world history of humankind is revealed before us – in one, but mainly its consequence as a natural, huge geological phenomenon" [15]. Of course, in order for the noosphere to emerge, it is necessary to unite humanity and consolidate the efforts of all inhabitants of the planet. V. Vernandsky believed that even by mid-20th century all prerequisites had existed: "For the fir t time in the history of humankind, we are in the conditions of a single historical process that covered the entire biosphere of the planet" [15]. At the same time, the Russian natural scientist was one of the first researchers to realise the necessity of transition to the new qualities and to the understanding that otherwise humankind will die: "Human being initially really understood that he is a resident of the planet and can, should think and act in a new aspect, not only in the aspect of an individual, family or kind, state or their unions, but also in the planetary aspect" [16]. Today, when global environmental, political, and other problems reach their peak of importance, these ideas pass a second birth. However, little is said about how exactly the transition to the noosphere is possible in V. Vernadsky's theories. According to the generalizations of F. Yanshina, the scholar formulated the following 12 conditions of noosphere existence in the future [17]:

1) human settlement over the entire planet;
2) abrupt transformation in the modes of communication and exchange between different countries
3) stronger connections, including political ones, between the Earth's states;

4) predominance of human geological role over other geological processes within the biosphere;
5) expanding the boundaries of the biosphere and entering the outer space;
6) discovery of the innovative energy resources;
7) equality of people of all races and religions;
8) growing role of people's masses in solving foreign and domestic policy issues;
9) freedom of scientific thought and scientific search from the pressure of religious, philosophical and political structures and creation of conditions favourable for free scientific thoughts in the social and state systems
10) increasing of the welfare of working people. Creating a real opportunity to prevent malnutrition, hunger, poverty and reduce the impact of diseases;
11) reasonable transformation of the Earth's primary nature in order to adapt it to meet all the material, aesthetic, and spiritual needs of the growing population;
12) exclusion of wars from the life of the humankind.

Nowadays, majority of the V. Vernadsky's necessary conditions required for transition to the noosphere, have been fulfilled partially or completely. The unity of civilization, living matter, biosphere and space, which is postulated in his works and those of other representatives of cosmism, is undoubtful. Specific mechanisms, as well as engineering solutions to enable transition of the terrestrial civilization to the innovative development level have been also proposed. Based on the existing research works, the most developed programme of such transition was presented in the works of A. Unitsky, the worldview component of whose views can be called the philosophy of planetary engineering.

B. Development of Russian Cosmism Ideas and Space Exploration Programme

Like his predecessors, A. Unitsky assumes that humanity is the result of the cosmic evolution. Being the carrier of the minds, from the very beginning the Earth human civilization has chosen the technocratic way of its development. Consequently, it enters the antagonism with the other living parts of the biosphere. This process is insoluble within the limits of separate planet. Technosphere is following the same way with the historical development way for the biosphere, specially, in its increasing influence on the lives of the terrestrial living organisms. "Plants, factories, power plants, machine tools, cars, and other engineering devices in the technosphere created by technocratic human are analogues of living organisms in the biosphere. They, like living organisms, exchange energy, information and matter with the environment, so, as well as organisms, must inevitably transform the nature around them" [18]. Ultimately, this process leads to the degradation of the biosphere – the process that can be witnessed nowadays.

Firstly, the antagonism of the biosphere created by nature and the technosphere created by human being using the nature of environmental transformations by its wastes. Wildlife has transformed a previously dead planet creating a living shell on it – biosphere, by means of its waste products – atmospheric oxygen and its derivative ozone in the ozone layer, humus and fertile soil and green fields and forests, etc. Industrial technologies, placed inside the already existing biosphere, generates various waste products which replaces the existing one – burning oxygen from the atmosphere and its replacement by greenhouse gases and thousands of carcinogens and poisonous substances, smog and acid rain, waste heaps and dumps of slag and ash in place of green fields and forests, rolled up in the asphalt and buried under the sleepers of fertile soil, etc., – sooner or later this process will lead to the degradation and extinction of life on the planet and return it to its original state – dead state, as the most comfortable conditions for the dead industry.

The humankind has two ways in this situation: further development of the industry on Earth and, as a result, creation of the inevitable disaster in the nearest future, or the removal of the industry outside the planet into near space to minimize transportation cost. The latter would allow not only to solve the growing environmental problems, but also to open new unprecedented opportunities related to obtaining access to the infinite spatial, mineral, and ene gy resources of the Universe.

However, it is impossible to transfer existing industry to the orbit relying only on the existing geocosmic vehicles (rockets) because of their extremely low efficiency and significant negative environmental impact, primarily on the ozone layer, which can be completely destroyed with frequent launches of the rockets. Other hypothetical transport systems, known in K. Tsiolkovsky time, such as, for example, a space elevator, are not able to provide sufficien cargo flow to achieve the mentioned purposes.

Alternatively, A. Unitsky proposed to use developed by himself General Planetary Vehicle (GPV) to support geocosmic transportation process [19]. It is a toroidal structure encircling the planet in the equator plane with two belt flywheels at its core. Accelerated by a linear electric motor, the flywhe l provides the necessary lifting force based on the creation of the excessive centrifugal force. Due to the second flywheel, which at a certain moment begins to move in the opposite direction to the first one, the GPV hull begins to rotate, gradually attaining the speed, necessary to overcome gravity and enter the space [19].

According to A. Unitsky's plan, the creation of the GPV will require consolidated efforts of the entire humankind. This is due to the fact that the landing-and-takeoff overpass goes over the territory of a dozen of the equatorial countries, as well as on the ocean under UN jurisdiction. Thus, the creation of the GPV may become that "common cause", which will unite humanity, as required by N. Fyodorov. However, in this case we are not yet talking about the immortality, which was proposed by the founder of cosmism, but at least about survival of the civilization.

Implementation of the large-scale GPV project will ensure the achievement of the goals proclaimed by K. Tsiolkovsky and V. Vernadsky. The civilization will get unlimited sustainable access to the space. It will be possible to perform interstellar and intergalactic flights, because the spaceships necessary for this purpose cannot be built on the Earth, but in orbit, and with the supply of materials that can provide the industry located there, it is possible. At the same time, the human population may increase almost infinitel , as problems with limited resources will

disappear completely. Probably, the same circumstance can contribute to the eradication of all wars (if the resources are infinite, then why kill each other for them?), the emergence over time of a single planetary state and everything else that stands, according to V. Vernadsky, attributes of the noosphere.

Due to the creation of the GPV, humanity will get an opportunity for a comfortable living conditions within the planet, as well as the transition to the space stage of its development and the formation of a space human. According to A. Unitsky, it is in engineering solutions that the mind praised by cosmists finds its practical application. "The world around us is created by engineers. Not bankers, not politicians, not artists, but engineers" [20], says the scientist. Accordingly, we can come to the conclusion that the transformative power of the mind is manifested exactly in engineering solutions.

The ideas of A. Unitsky and, in particular, the concept of the GPV, inherit the traditions of Russian cosmism and contains a significant moral and humanistic potential. At the same time, these ideas are a fundamentally new step forward in relation to all its predecessors, as they have a deep scientifi and engineering foundation, meeting the requirements and demands of our time.

The direction of thought, set by representatives of Russian cosmism and received qualitative development in A. Unitsky's work, is a foundation of formation of the new integral philosophical system capable not only to unite efforts of scientists in this area, but also to generate the worldview foundation for the formation of a new harmonious type of relations in the system "Human being – Wildlife – Technologies".

1.7 Ecological Footprint Analysis of Modern Space Exploration Technologies

Nowadays and in the near future, the geocosmic transportation is an expensive transportation method with the cost of at least 1 mln USD/t. This cost takes into account the capital and operating costs even with the most ambitious forecasts. Therefore, to implement the space industrialization programme utilising the existing and near-future prospective transportation systems, an annual budget of at least 100 tln USD will be required. It is hard to justify such cost for the humanity, as it exceeds today's global GDP. These costs are actually leading to the civilization suicide, since the vast majority of the funds will be spent on creation of the tools for the large-scale destruction of the biosphere by the geocosmic transport system. The evidence of that can be seen on the example of launch vehicles and their footprint, including the future-coming solutions [19].

The environmental harm of the rockets is worth to be analysed separately. Modern programmes are led by the rocket-driven space industrialization and exploration of the Moon and Mars and the leading experts support these approaches. The rocket launching programmes lead to the creation of the ozone holes, development of the ionosphere holes with the further stream of the high-energy particles being directed to the surface of the planet. Such streams generate turbulence in the upper layers of the atmosphere, provoke powerful atmospheric cyclones, and drastically reduce the atmospheric pressure at the surface of the Earth, etc. In the given analysis, the main concentration is on the destruction of the ozone layer.

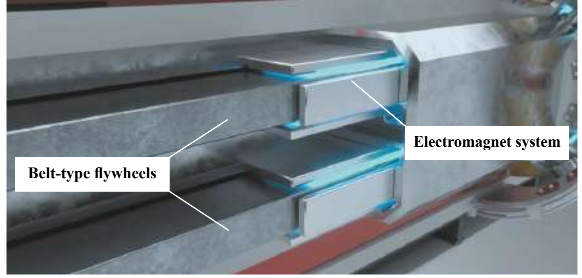
Back in the early 80s of the last century, there were evidences that more than 60 % of the ozone in the ozone layer of the planet was destroyed in the process of the rocket launches. For example, launch of one shuttle vehicle, depending on the ionosphere's conditions, can destroy from 10 mln to 40 mln tons of ozone [21]. It occurs because such vehicle uses ozone-extinguishing elements as fuel (nitrogen, chlorine, etc.). Furthermore, the jet stream has the presence of the plasma with the temperature of about 4,000 °C, which is almost three times the steel melting temperature. In addition, this plasma has an outflow speed of about 4 km/s, which is fiv times higher than the speed of a sniper rifl bullet. Thus, almost the entire energy of the burning fuel in jet engines is released into the atmosphere, and only a small part of it is spent on useful work: to lift the cargo to the altitude of the orbit and its acceleration to the first cosmic velocity, which is the required orbital velocity for the near-Earth orbit.

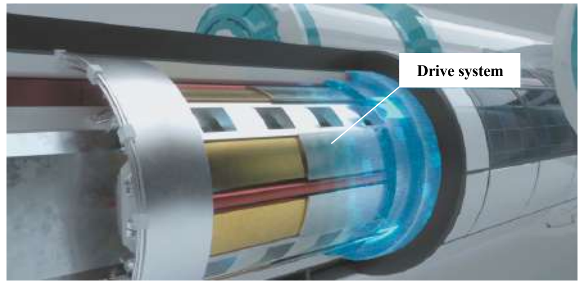
In addition to the ozone quenching, the rocket launches also change the physical chemistry composition of the upper atmospheric layers, cause turbulence in the ionosphere, and affect the geomagnetic field within the pitch of the launching plane.

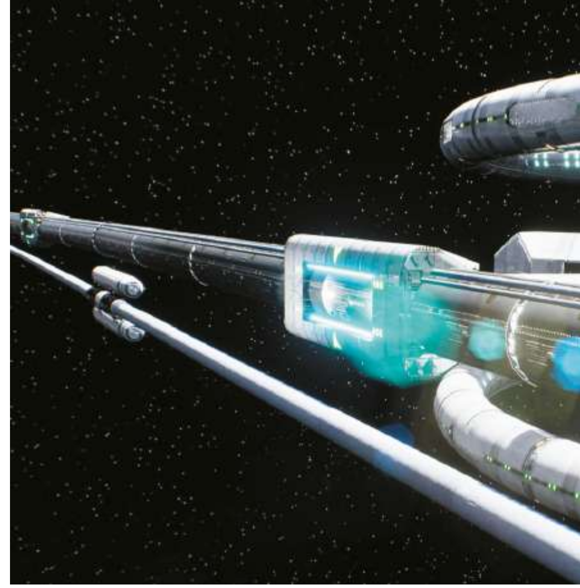
It is difficul to determine the combined economic damage caused to the planetary ecosystem by the traditional rocket space exploration. It is possible to assess this damage by estimating the industrial-based ozone recovery process, instead of assuming natural recovery, which is seen as "free" and "gratuitous".

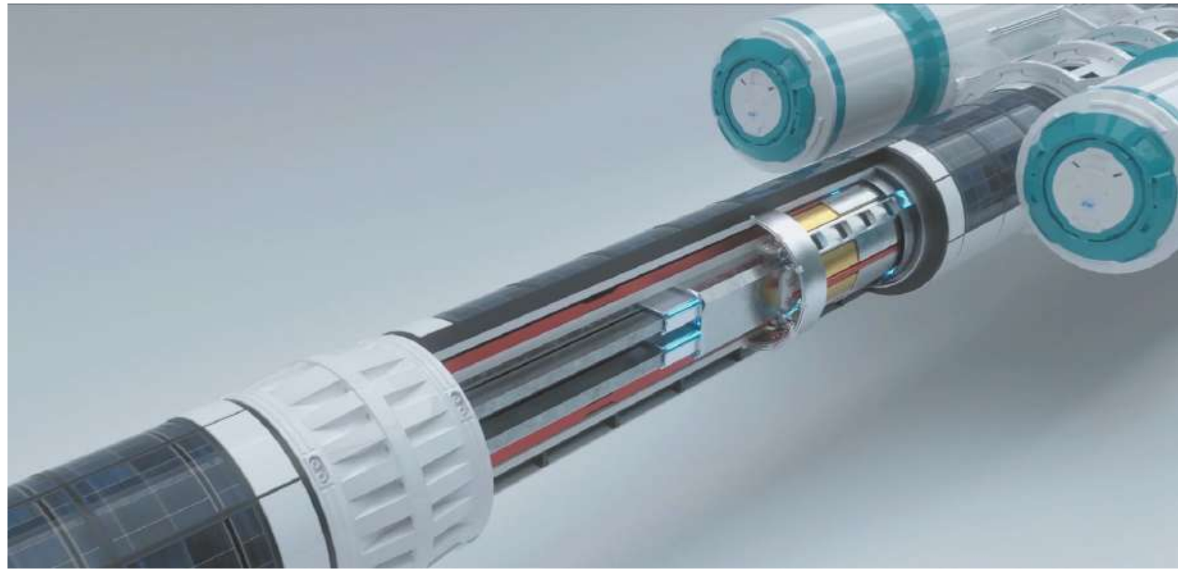
It is a common knowledge that ozone is produced from the air, being passed through an ozonizer. Cost of the ozone production depends on the electricity prices, as this process has high-energy consumption. The best industrial ozonizers consume about 10 kWh of energy to produce 1 kg of ozone [22]. With an average world cost of electricity of about 0.1 USD/kWh, the cost of electricity consumed to obtain 1 ton of ozone will be approximately 1,000 USD in energy. Considering the cost of equipment and the overheads, the cost will be significantly higher for the large-scale application.

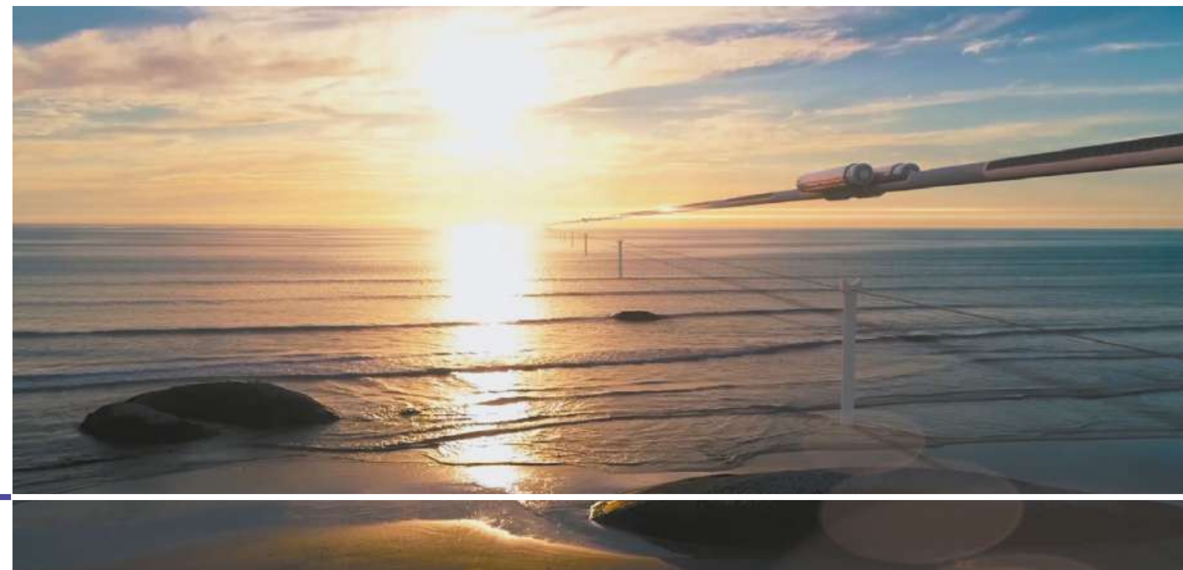
Considering, that one launch of the rocket leads to the consumption of more than 10 mln tons of the ozone, recovery of it will cost about 10 bln USD in electricity prices. Even if each rocket moves 100 tons of cargo into the orbit, which is more, than the current cargo capacity of the rockets, the environmental damage of at least 100 mln USD will be incurred per 1 ton of the payload. Consequently, the minimum environmental tax on development of the near-Earth space using the launch vehicles should be at least 100 mln USD for each ton of the output cargo. There is no prospective reduction in the cost of launching rockets, which can reduce the cost of moving a ton of cargo into the orbit below 100 mln USD. This cost will cover the harm that will be even more sensible in the future, as more rockets will cause it to our common home – the planet's biosphere.











1.8 Development Limits and Industrialization of Space as the Only Possibility for Its Continuation

The history of civilization's development is, to a great extent, the history of the space conquering and resources developing. The possibilities of further sustainable development of humankind are determined by its ability to discover new spaces and new deposits of resources outside of the Earth, as the opportunities available on the planet are already insufficient to maintain the current growth rat

Even assuming that 100 % of all countries in the world switch to renewable energy sources, a number of problems will remain unresolved. This list includes exhaustibility of some vital resources, such as fresh water, in large quantities consumed and polluted by the terrestrial industry, and the impossibility of creating a completely waste-free industrial production process.

The feasible alternative to the space exploration to ensure further development of civilization can only be an enforced restriction of production and consumption, limitation of the birth rate, etc. But even if these conditions are implemented, many scientists stated a hypothesis that the possibilities of human civilization growth have limits, which in scales of a single planet seem to be insurmountable.

A. Growth Limits

In 1972, a group of scientists under the supervision of D. Meadows from the Massachusetts Institute of Technology proposed a mathematical model of global development. Its task was to predict what would happen to civilization if the trends of demographic growth, industrial development and environmental pollution remained at the same level or they would surpass the indicators available at the time of work being carried out. The results of the study, summarised in the book "The Limits to Growth", were disappointing. "According to the forecast of D. Meadows and his colleagues, humanity was confidently heading towards a catastrophe that could not have been avoided only by taking measures to limit and regulate production growth and change the criteria of the progress. The book stated that material growth could not continue indefinitely on a physically finite planet and demanded to abandon the increase in quantity (growth) in favour of quality (development)" [23].

The model consisted of nine main variables and 30 auxiliary variables related to each other by non-linear differential equations. Primarily, results were calculated for non-renewable resources consumption, industrial measures, agricultural resources, service market size, free land, agricultural lands, urban and industrial lands allocation, unresolvable pollutants and population. There have been calculated 12 scenarios of the humankind development, which would be implemented in life for the currently maintained conditions, or when taking measures related to the probability of new technical opportunities, political and social decisions. Five out of 12 scenarios, including the baseline scenario, predicted the growth of the population to 10–12 bln and the subsequent sharp catastrophic decline to 1–3 bln with a significant deterioration in living standards, up to a return to a primitive state. Relatively favourable scenarios included actions, like active restrictions on the birth rates and capital investments as mandatory conditions. But even assuming the discovery of an unlimited source of energy and eff ctive pollution control, it was found that the limit of humankind population is around 10–12 bln, at which it would stabilize itself with lower consumption rates in comparison with the current trend.

The model created by the researchers was validated by observing the key indicators after set time periods. In 1992, and then in 2004 and 2012, scientists published three more books, clarifying and complementing the first one: "Beyond the Limits to Growth", "Limits to Growth: The 30-Year Update", "2052: A Global Forecast for the Next Forty Years". It was confirmed that the real development, in general, is in line with what was predicted in 1972. For example, the predictions of population growth from 3.7 bln in 1972 to 6 bln in 2000 was achieved in reality. The scenario showing an increase in world food production (in grain equivalent from 1.8 bln tons per year in 1972 to 3 bln tons per year in 2000) also almost coincided with the real figures. However, the study in 1992 raised some new ideas. The authors found that "humankind has already gone beyond the limits of self-preservation of the Earth" [23]. This fact was brought out by them in the title of the second book. By 2004, the situation had deteriorated even further. The only scenario acceptable at the given moment, according to the researchers, is the "Growth Restriction + Advanced Technologies" scenario, which includes the following steps:

- limiting of the birth rate (no more than two children per family since 2002), with the goal of smoothly stabilizing the Earth's population at 8 bln people mark by 2050;
- improving technologies with the aim to reduce consumption of non-renewable resources per unit of industrial output by 80 % and emissions of contaminants by 90 %;
- containment of production growth for goods and services per capita, with smooth stabilization of production volumes;
- increasing yields in agricultural products, with a gradual transition to more environmentally friendly technologies.

The theory of limits to growth has inspired a number of studies with similar hypothesis testing ideas, prompted countries to take measures to prevent the rapid catastrophic consequences of uncontrolled growth in production and resources consumption. Based on these theories, a number of international environmental agreements have been adopted and the goals of sustainable development has been postulated. Today, there are almost no doubts regarding correctness of the growth limits theory. However, by 2020 it is possible to observe that the conditions necessary for the implementation of favourable scenarios are being met to a very limited extent, or not at all, because for most countries this would mean a halt to development. No one is ready to follow these steps, thus, the current state of affairs will remain unchanged. It means then the global cataclysms associated with exceeding the "limits", will occur during the current human generation. The reaching of the limits might be observed in the COVID-19 pandemic.

B. Unlimited Growth

The model created by D. Meadows and his group is based on the limited fossil and spatial resources of the planet. Under these conditions, no measures can support limitless development of civilization. The only solution with the limitless resources includes large-scale transition into space, beyond the boundaries of the planet. Reducing the population to one billion is not an abstract thing. Six to seven billion people will have to die. And the only large-scale industrial exploration of space will allow us to avoid this catastrophic prognosis. This development direction will not only provide platform for the population and industrial capacity growth, but also it is a matter of survival.

Space provides inexhaustible reserves of raw materials, endless energy and space resources, as well as fundamentally new technological capabilities – weightlessness and ideal cheap vacuum. If a civilization manages to get access to these commodities, the necessity to take into account existing limits to growth will disappear. It will remove any boundaries on the population numbers. And although the suitable land size for settling and growing food on Earth remains limited, hypothetically there is a possibility to add them in the near-Earth space through the creation of appropriate infrastructure. At the same time, in the outer space, agriculture products (for example, in terms of energy costs) may be even more profitable than in familiar environm nt.

Beyond the atmosphere, the conditions for the majority of the technological processes are much better than on Earth. Solar energy, which intensity of radiation will not change at least in the next 5 bln years, will be able to power large number of various industries. The weightlessness and vacuum will make it possible to produce traditional products of much higher quality, as well as fundamentally new products that cannot be obtained on the planet. The celestial bodies are rich in a variety of chemical elements. At the same time, industry in space will not harm the living nature, concentrated in the biosphere of the planet, as it will be distant from it. If an environmentally dangerous part of the industry is removed from the Earth, its conditions will improve dramatically from the point of view of the living nature. Vast territories, which are occupied and adversely affected by modern cities, factories and roads, will be liberated. But people, as it was already mentioned, will be able to settle not only on the Earth, but also in the orbit in the near space with the possibility of moving to the further cosmos in the future. It will also enable the possibilities of looking for and colonization of other potentially liveable planets.

For large-scale space exploration it is necessary to create a fundamentally new geocosmic transport, which will make it possible to carry out transportation on the route Earth – Near-Earth Orbit – Earth in an amount sufficien to meet the needs of the multibillion population of the planet. Only A. Unitsky's General Planetary Vehicle can fulfi these needs out of all existing technical solutions [19]. This system represents a toroidal tubular structure with a cross section of one metre, encircling the planet in the equatorial plane. Belt flywheels supported by magnetic levitation system (which are accelerated by linear electric motors to the cosmic velocities, giving the transport the necessary lifting force) are positioned inside the vacuum channels of the construction with the total length of 40,000 km.

The flywheels not only provide for the ascent to the orbit, but also spin around the planet the GPV's hull with passengers and cargo to the first cosmic velocity, which is the key requirement to enter the designated orbit. "It will take about one million years to achieve what the GPV can do in one year, with a modern world rocket and space industry, in which trillions of dollars have already been invested" [20].

The author argues that the humanity already has all technologies for creation of the GPV. "Almost all engineering solutions used in the project are widely known, have been tested in practice and are now implemented in industry. The budget of the project will be about 2.5 tln USD. This is not much, if we take into account that the annual U.S. military budget today is almost 700 bln USD" [20]. Moreover, it is not much if we take into account the price of the question – survival of the Earth technogenic civilization today and ensuring its sustainable development tomorrow.

When civilization will be able to support transportation of hundreds of millions of tons of payload annually between the Earth and the orbit at a reasonable price, then the developed industrial, economic and residential infrastructure will emerge in a very short time on the orbit. In the future, its scale may significantly exceed the current scale of the industry. Engineer A. Unitsky also developed a model of orbital settlements. It is assumed that the personnel of orbital manufacturing facilities will live in EcoCosmoHouses (ECH). "The best part of the Earth's biosphere with all necessary natural conditions: atmosphere, diversity of landscapes, living organisms, soils, biogeocenosis, aquatic ecosystems, etc. will be recreated in ECH designated for several thousand inhabitants, in a small community like a village built on innovative principles. Comfortable physical conditions will be created within ECH: gravity (using centrifugal forces), illumination in the natural spectrum, optimal temperature, pressure, and humidity" [24].

In future such space houses carrying biosphere can become the basis for creation of interstellar long-range ships which will explore the deep space in their mission of finding liveable planets. During such travels, which can take hundreds or even thousands of years, there will be a natural development of microcommunities with presented change of generations. People will be able to spread not only within our Solar System, but also throughout the galaxy and even the Universe. This will be the final exodus of our civilization beyond any limits of growt .

C. Conclusion on Development Limits and Industrialization of Space

The removal of ecologically dangerous part of the terrestrial industry into the near-Earth space will lead to the expansion of the industry and civilization development in general practically with no limits, to become the basis for further sustainable development of a humankind for thousands of years ahead. In order to more clearly demonstrate the potential that comes together with the idea of creating the GPV and industrialization of the near space, in-depth analysis carried out within the framework of this section. In future, it is necessary to consider in detail the capacity of the near-Earth equatorial space – amount of resources – raw materials, energy, technological and other, as well as industrial, residential, agricultural, and space infrastructure resources, that it will be able to produce and accommodate.

1.9 Analysis of the Space Industrialization Development Strategy

The location of the extraterrestrial industry is also an important factor. It should be as close as possible to the consumers, i.e., to the surface of the planet, where billions of people live. Since the industry will include a huge number of elements, such as factories, technological platforms, power plants, residential modules, etc., their motion trajectories should not intersect. Otherwise, given high values of the cosmic velocities, a destructive chain reaction of the entire system (the domino principle) may occur, which will cause death of thousands, if not millions, of people serving the space industry. Probability of such a catastrophe is not equal to zero, even with the use of the most advanced control systems. To reduce probability of an accident, industrial systems should be located in the equatorial plane of the planet.

With the equatorial placement of the industrial elements, the directions of the velocities of the arbitrary bodies at the arbitrary time, located on the same vertical line, with respect to the planet's surface, are parallel to each other. The altitude of the orbit, in this scenario, will have no impact on the direction of the velocities. Furthermore, the module of the velocities in the neighboring orbits has smaller differentiation. It leads to the significant reduction of the possible intersection of the motion trajectories. In the emergency, space systems will be touching each other with the small velocity difference in comparison with the collision interactions in the alternative solutions. It will also lead to the simplifi ation of the possible exchange processes of raw materials, energy and products between the systems within the neighboring orbits.

Thus, the principle of exploration of the near-Earth space in the future in the equatorial plane is shown in Figure 1. It differs significantly from the today's space exploration with the arbitrary directed orbits of the satellites and space stations, shown in Figure 2.

Surface of the Earth can be seen as the source of the gravitational potential. It is possible to overcome it by approaching infinite altitude or reaching the firs cosmic velocity of 7,919 m/s. Furthermore, such velocity will lead to the circular motion on the orbit, but not to the motion, normal to the surface of the Earth. Therefore, for each ton of cargo delivered into the orbit, it is necessary to supply at least 8,700 kWh of energy. It is equivalent to the consumption of about 2.2 tons of fuel used in the thermal electrical power plant.

To avoid significant environmental damage by the geocosmic transport, such systems should have efficienc as close as possible to 100 % due to the very high basic energy consumption. For example, a launch vehicle spends 20 times more fuel than the fundamental laws of physics require. Majority of the wasted energy, which is not supplied to the payload, is being exhausted into the atmosphere. And taking into account the pre-flight (obtaining the fuel components, their cooling to cryogenic temperatures, etc.) and flight costs, as well as the energy losses (the aerodynamic resistance, loss of lower stages and fairings, which manufacture consumes a huge amount of energy, etc.), the overall energy efficienc of the launch vehicles is significantly lower than that of a steam locomotive, and it is equal to about 1 %.

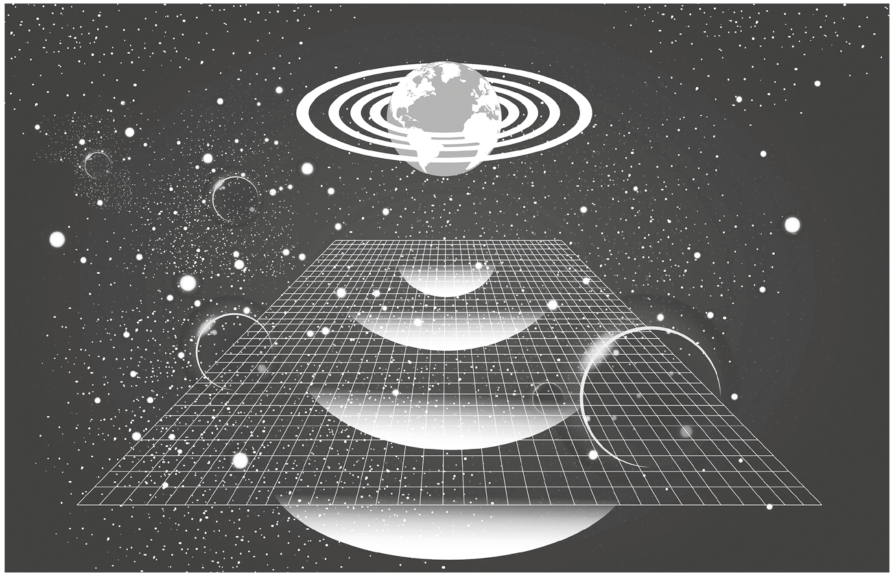


Figure 1 – Space exploration in the future

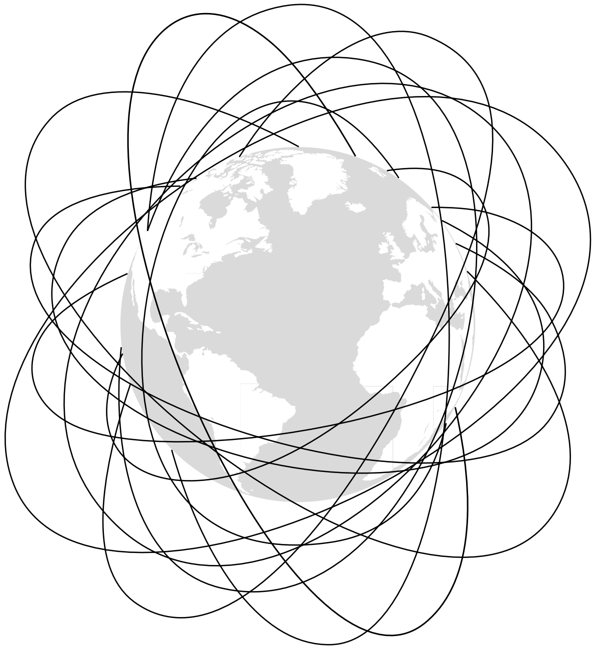


Figure 2 – Space exploration nowadays

When the atmosphere decelerates, the cargo returns from the space to the Earth, the space vehicle, thus all their potential and kinetic energy is released into the environment in the form of high-temperature plasma wake of the burning heat-shielding shell, followed by the acoustic waves. These processes increase the environmental damage caused by the initial geocosmic logistics processes.

It is hard to predict the technological development, including development of the space technologies, and foreseeing future discoveries. The only thing can be stated with complete confidence is that, whatever this technique may be, it will comply with the fundamental laws of nature. Such laws, repeatedly tested in practice, will remain fair at all times. In the field of mechanics, there are four conservation laws, which can simplify any other particular case. These laws include laws of conservation of energy, momentum, angular momentum, and motion of centre of mass for the closed system.

In addition to the kinetic and potential energies, space cargo should be supplied with the momentum and the angular momentum to generate rotational motion in the orbit of the planet. The near-Earth space industry is going to be created from the planet' surface. Based on the conservation laws there are several impacts occur: excess of the energy, which equals to the difference between 100 % and efficienc of the rockets; reversal impulse, equal to the change of the linear momentum divided by the launching time; and the angular momentum, similar to the operation of the helicopter. These processes are transmitted to the planet. For example, a rocket transmits all of this to the planet, not to the surface directly, but through an intermediary, represented by the atmosphere. Rocket interacts with the planet by throwing combustion products into atmosphere at a speed of about 4,000 m/s and with a temperature of about 4,000 °C. These processes occur in the most vulnerable parts – in the ozone and ionosphere layers. This causes turbulence, atmospheric and ionosphere vortices. Each time a rocket is launched, it forms ozone and ionosphere holes with the areas equal to the size of France.

1.10 Technical Foundation of Non-Rocket Space Exploration

Not only the ultra-high temperatures and the jet flow rates cause many shortcomings of the rockets, but also by the ultra-high engine power requirement, which reaches about 1 mln kW per ton of cargo. Imagine, for example, how much would a regular passenger car cost with an engine not with a power of 100 kW, but 1 mln kW? Reduction of the power requirements for the jet engines can be achieved by increase of their effective operating time from 4–6 min currently to 120–150 min. Furthermore, it would reduce acceleration from the current 30–50 m/s^2 to 1–1.5 m/s2, which is an acceptable number for an ordinary passenger, as well as for the traditional transportation systems. Unfortunately, such change cannot be done, because, according to the laws of physics, the jet thrust would decrease with a decrease in the intensity of fuel burning process, which during the flight should always exceed the starting weight of the rocket, thus all rocket fuel would burn and the rocket would stand on the launch platform without even moving.

Thus, the basic conditions and requirements for space industrialization and geocosmic transport can be formulated as follows:

- space industry should be placed in low circular orbits in the equatorial plane;
- geocosmic transport should be designed not as a fix d structure, but as an aircraft;
- it should have limited interactions, both mechanical and energy-based, with the atmosphere, so it could rely on the internal forces and be environmentally friendly;
- theoretical efficiency of geocosmic transport should be close t 100 %;
- it should have cargo capacity of, initially, millions, and in future, billions of tons of cargo annually;
- it should have the capabilities to recover the energy excess of the space products during its delivery from the space to the Earth;
- geocosmic transport should rely on the clean energy, primarily electric;
- it in the process of geocosmic transportation should transmit momentum, angular momentum and energy directly to the solid Earth's crust, without including mechanical interactions with the planet's atmosphere;
- power of the geocosmic transport engine in terms of 1 ton of cargo should not be exceeding 100 kW, as it is in a passenger electric car;
- acceleration rates for passengers and cargo should be within the comfortable range and not exceed 1.5 m/s2 To achieve that, the time to get to the orbit and reach the first cosmic velocity should be more than 2 hours

1.11 Overview of the General Planetary Vehicle

All of the above 10 basic requirements are met by only one engineering solution, which is the General Planetary Vehicle. It is presented in a form of a self-supporting aircraft (Figures 3, 4), covering the planet within the equatorial plane [25].

The uniqueness of the GPV operation is seen in the way of reaching the outer space. It happens by the increasing in the diameter of the ring (by 1.57 % when lifting every 100 km) and reaching at the calculated altitude (with passengers and cargo) the peripheral velocity of the body, which should be equal to the first cosmic velocity. At the same time, the position of the centre of mass of the GPV does not change in the elevation process and it always coincides with the centre of mass of the planet. Therefore, the movement (rising to altitude and receiving the first cosmic velocity at a given altitude) can be carried out relying on the internal forces of the system, without significant interaction with the environment

The optimal internal driving force for the GPV is the excessive centrifugal force from a belt flywheel accelerated in a vacuum channel using a linear motor and a magnetic cushion to speeds exceeding the first cosmic velocity up to 10–12 km/s,

Figure 3 – GPV combined with Unitsky String Technologies (UST) transport system (visualisation)

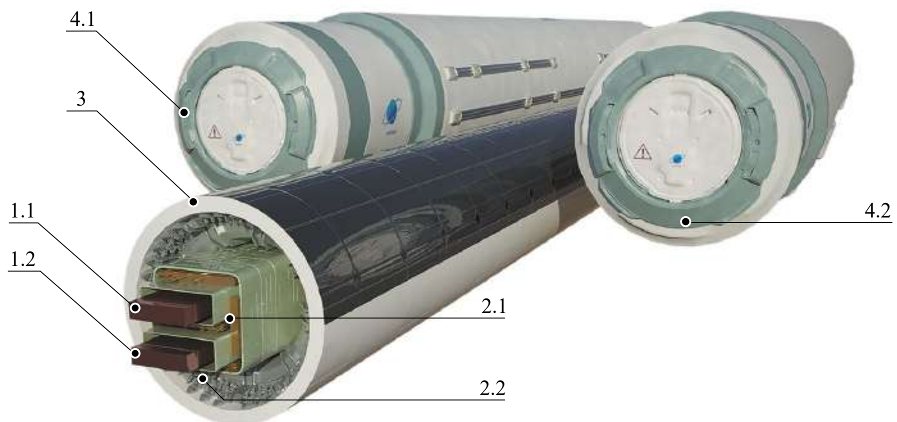


Figure 4 – GPV design: 1.1 and 1.2 – belt flywheels;
2.1 and 2.2 – magnetic suspension systems and linear electric motor;
3 – body; 4.1 and 4.2 – containers with cargo (visualisation)

depending on the ratio of the linear masses of the body and the flywheel. Such velocity is thousand times lower than the speed approaching 300,000 km/s, obtained on the same principles in the modern charged particles accelerators.

To transfer momentum and angular momentum to the body of the GPV in the process of orbit's approach in order to obtain the first cosmic velocity at a given altitude, a second belt flywheel is needed. Then, during the braking process of the first belt flywheel, its excess kinetic energy, since the linear electric motor will be operating in the generator mode, will be recovered in the form of acceleration in the opposite direction of the second flywheel instead of being wasted to the environment. When a double pulse is received (from acceleration of one and braking of the other flywheel), the maximum overall efficienc of the GPV will be achieved while rising to the orbit and reaching a peripheral velocity equal to the first cosmic velocity of the body with passengers and cargo.

Thus, from the standpoint of physics, the most environmentally friendly geocosmic aircraft, using predominantly its internal forces to enter space, has only one possible architecture:

- structure of three rings covering the planet in the equatorial plane with the centre of mass coinciding with the centre of mass of the Earth;
- ring structures with the ability to rotate around the planet and relative to each other with velocities exceeding or equal to the first cosmic ve ocity;
- ring structures with the ability to lengthen with the increasing diameter in the process of reaching their orbits;
- ring structures with linear actuators along their length, capable of accelerating and decelerating them, relative to each other.

Thus, the GPV is a concept of the reusable geocosmic transport complex for non-rocket development of the near space. The GPV allows to put into the orbit within one flight a mass of about 10 mln tons of cargo (250 kg per 1 m of the GPV body length) and 10 mln passengers (250 people per 1 km of the body length), which will be involved in creation and operation of the near-Earth space industry. Within one year, the GPV will be able to go into space up to 100 times. To achieve similar to the annual goods and passengers flow of the GPV by the modern rocket industry, it would take about a million years. At the same time, the cost of delivering each ton of payload to the orbit will be thousand times lower than that of the modern launch vehicles reaching the number of less than 1,000 USD/t.

The environmentally friendly GPV operating exclusively on electric energy will allow realising industrialization of the near space. To do this, it will be necessary to close all the industrial productions that are harmful to the Earth's biosphere and recreating them again in the near-Earth orbit using new principles, which are environmentally friendly for the outer space. This step will open access to the fundamentally new industrial technologies with unique space capabilities, which are not available on the Earth: weightlessness, high vacuum, ultra-low and ultra-high temperatures, inexhaustible sources of energy and resources, including mineral and spatial ones. Big opportunities will be also opening up in the field of information and energy communications technologies.

1.12 Key Elements of the Space Industrialization Programme

The General Planetary Vehicle is the key element of the entire space industrialization subprogramme – SpaceWay. Its main goal is to move the environmentally harmful industry from Earth to Earth's orbit for the sake of preserving and restoring the ecology of the Blue Planet.

Developed SpaceWay subprogramme implementation includes three main infrastructure components (Figure 5):

- Equatorial Linear City (ELC);
- General Planetary Vehicle;
- Industrial Space Necklace "Orbit" (ISN "Orbit").

The Equatorial Linear City is an extensive network of residential and industrial clusters united by various means of communication, used for the delivery tasks for the goods, including suborbital deliveries. Central axis of the ELC is located within the equatorial plane on the land and sea. These ELCs are carrying launching platforms for the GPV. Passengers' cargo transportation is organised by UST high-speed ground transport, as well as a network of hyper-speed transport – Umach. Umach is a transportation system, in which the rolling stock moves in a fore vacuum tube to significantl reduce air resistance and achieve operating geocosmic of 1,250 km/h.

The General Planetary Vehicle is a reusable self-supporting aircraft operating on the route Earth – Orbit in a cycle manner. The structure encircles the Earth in the equatorial plane. The take-off and landing processes are served by the overpasses. The system is driven by the centrifugal forces resulting from acceleration of the flywheels driven by linear electric motors located in the GPV's core.

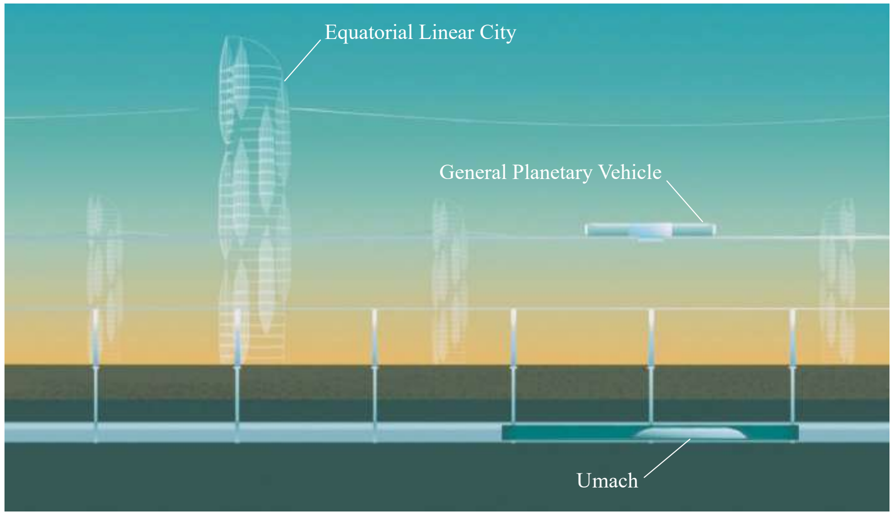


Figure 5 – Key elements of space exploration

Cargo payloads and passengers are accommodated in special modules attached to the GPV hull and distributed along its length. Communication between them is done using the UST and Umach transportation systems.

The price of a passenger ticket to the Earth' orbit will be about 100 USD. Furthermore, the GPV will provide high level of comfort, which will be higher, then for the land transportation. Low prices can be achieved because of two reasons: relatively low operation costs of the GPV and high transportation numbers per one travel of passengers and goods.

ISN "Orbit" is a network of industrial and residential facilities located within the low orbit in the equatorial plane. This network includes space-based factories, manufacturing facilities, power plants, and residential space settlements – EcoCosmoHouses for the servicing staff of the space industr .

The transportation systems, energy links and information communication channels interconnect elements of ISN "Orbit". Space industry is connected with the Earth's surface by the GPV. As expanding the GPV reaches targeted orbit, cargo and passengers can be unloaded into the complex, which surrounds the entire planet.

In order to generate artificial gravity, residential facilities are having continuous rotation about their axes. To achieve stable location of the axes, shapes of the facilities should follow one of the rotational shapes: a sphere, a cylinder or a torus.

Living spaces are set up inside the carrier shell, made of high-strength materials. These areas also include a layer of a soil and the breathing environment, similar to the Earth's atmosphere. Meteoroids and radiation protections are placed outside and inside the structures.

EcoCosmoHouse is a space structure with an autonomous biosphere. Each ECH has artificial gravity and adjustable environmental parameters. The ECH's biosphere can provide autonomous living space for up to 10,000 people (Figure 6).

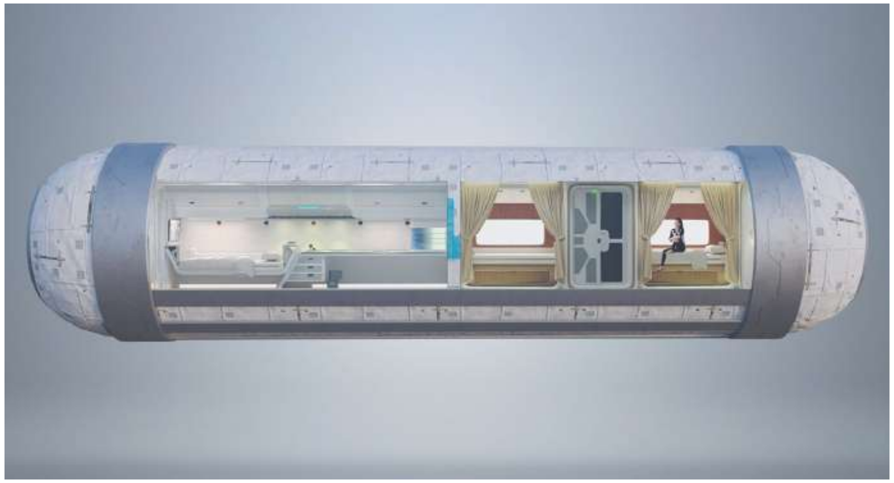


Figure 6 – ECH representation

Passenger and cargo modules of the GPV can be used not only for the transportation purposes, but also for the full-fledged housing. Several modules might be combined in separate residential clusters of the ECH, similar to the modern suburban areas with the living spaces for each family.

Implementation of the SpaceWay subprogramme is possible in the near future with the modern level of science and engineering knowledge. This will require significant investments, as well as combined efforts of the researchers and inventors. However, the consumed resources will be replenished, since the programme opens access to the unlimited energy, special and material resources of the outer space for humanity. In addition, SpaceWay will allow to gradually get rid of harmful industrial enterprises on Earth, which will result in the restoration of its ecology.

1.13 Conclusion

Taking the industry out of the planet will radically improve our common living environment, and the biosphere of the planet Earth, especially in the heavily industrialized regions, without applying any restrictions on production growth.

Majority of the required engineering solutions, required to produce the project of the GPV, are widely known, tested in practice and they have been currently implemented in the industry. The overall project budget will be about 2.5 tln USD. This is not a substantial amount, given that the annual military budget of the United States is reaching 700 bln USD. Initial base for the launch overpass will be based on the string transportation systems of UST. It will improve the profitability of the project by adding ground-based transportation capacities for the passengers and cargo.

The material capacity for this project is currently feasible. For example, it will require about 100 mln tons of metal alloys, as of today the same amount of steel is smelted on the planet in less than three weeks, and about 10 mln m^3 of reinforced concrete, which is equal to the amount of the concrete used in a single dam of the Sayano-Shushenskaya Hydro Power Plant. Integration of the GPV project into the world power grid will result in the additional 100 mln kW of additional consumption, based on the estimates of 2.5 kW per running metre of length, or 10 kW per 1 ton of cargo. It is less than 2 % of the installed net power of the electrical plants in the world and it is equal to the power of one launch vehicle that is capable to lift into the space less than 100 tons with one flight, unlike 10 mln tons of cargo carried by the GPV.

Introduction of the network of the linear cities with millions of the workplaces, which can be built along the GPV overpass and that can pass the oceans with application of the UST transport and infrastructure complexes, such as urban (up to 150 km/h), high-speed (up to 500 km/h), and hyper-speed (up to 1,250 km/h), will allow the commercialization of the SpaceWay subprogramme to begin even before the terrestrial industry is put into space.

String-based transportation complexes are already capable of earning money. People are able to build residences and develop businesses around them. Innovative environmentally friendly transport will make life even more attractive in the area of the transport accessibility. The string transportation complexes will give an impulse to the development of the previously undeveloped areas and regions. Thanks to the UST overpasses, the modern modes of information communications, power lines, clean water supplies and fertile soil, and later on, the space-made production will have capability to reach the most remote corners of the planet. Relocation of the life towards the transportation systems will significantly reduce amount of the deserted land. Living complexes in the mountains or on the sea shelfs will be more prestigious than, for example, the real estate in New York or Paris. The civilization and the nature will reach harmony with each other.

Besides linear cities network development, the research work on the GPV will be carried out. These activities will require about 5 % of the total project investments. Generally, it will take at least a couple of decades to address all the engineering problems [26].

There is a strong believe that such a global geocosmic programme with variety of the common goals and objectives is able to unite all countries of the world and attract their resources to support this super-ambitious project, designed to save the humanity. From the general architecture of the GPV, its construction will directly affect the territories of dozens of countries, especially located along the equator. Furthermore, it will affect the political and economic life of the entire world. The GPV and the industrial necklace around the Earth will become an indispensable platform for advanced exploration of the deep space by reusable space vehicles, and a security circuit to prevent the space threats, including the meteoritic ones. The project implementation period will take about 20 years, taking into account the socio-political discussions, research, and development, design, surveying, construction, and installation works.

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2 Analysing Prospects of Employment of Rockets and Non-Rocket Geospace Transport Technologies for Space Industrialization

2.1 Introduction

Space industrialization is not just prospective, but also indispensable for today. Space contains inexhaustible resources of energy and expanse area and provides unique technological conditions such as weightlessness, vacuum, cleanliness, ultrahigh and cryogenic temperatures, etc. Herewith, if the current rates of economic growth and technologic progress stand the same, then destroying, polluting, and disbalancing of all ecosystems and depletion of natural and mineral resources will be so intensive two-three generations from now, that Earth may become unfit for human civilization.

However, space industrialization is possible only upon employment of effe tive and environmentally clean geospace transport system performing transport tasks of space industry. Current rockets are one of the most ecologically dangerous and energetically unfavourable geospace transport technologies, and cargo traffic provided by the rocket-space industry is extremely limited. Analysis of known non-rocket geospace transport technologies such as space elevator, space cannon, and their varieties, including usage of space tower, shows that in comparison with rockets they are of the same ecological danger and are poorly engineered, as well as their capacity is not signifi antly larger than launch vehicle perform.

The present paper also reviews the General Planetary Vehicle (GPV) [1] designed by engineer A. Unitsky which complies with the requirements of zero energy loss during payload geospace transport operation. Comparison of current solutions and innovative ones being developed will make it possible to choose the most effe - tive transport infrastructure technology for space industrialization.

2.2 Analysis of Geospace Transport Technologies

2.2.1 Current Rocket Space Industry

Launch of the firs space satellite Sputnik-1 took place on October 4, 1957, i.e., more than 60 years ago. And the used launch vehicle with thermochemical engine hadn't underwent any significant changes and technological improvements in a number of decades. Structures of burners, fuel pumps, ways to feed components of rocket fuel, management systems, types of used rocked fuel, and so on had changed. But its operational principle remained the same, which is interaction with working fluid formed in the result of burning or chemical interaction between components of the fuel then flowing out of the engine with the higher temperature much more rapidly, and in accordance with the impulse law forms a reactive thrust pushing the launch vehicle with the payload in the contrary direction. There is no possibility to change anything in thermochemical rocket engine, as well as in the entire rocket geospace transport system. The launch vehicle will remain an environmentally dangerous and energetically inefficient geospace transport vehicle

In order for the payload to be considered delivered to space, it must break Earth's gravity. This can be performed by its raising to one of the Earth circular orbits and providing with the required circular orbital velocity similar to the first cosmic one, when the centrifugal and gravitational forces are equal and the cargo is unaffected by gravitation and becomes the Earth satellite. According to the laws of physics, minimal energy that has to be spent to lift a ton of cargo and to provide it with the first cosmic velocity, for example, 7,919 m/s, equals to 8,700 kWh of energy. Nevertheless, the rocket consumes 20 times as much energy for the transportation than required according to the laws of physics. In the course of the launch vehicle raising, all energy of its thermochemical engines is discharged into atmosphere. And the capsule, during freefall launching from space, reenters with deceleration the dense layers of the atmosphere, and all its potential and kinetic energy is also discharged likewise in the form of high-temperature plasma wake. In either case, the atmosphere gets heavy chemical, high-temperature, acoustic, turbulent, and other pollution. Thus, the total power efficienc of the launch vehicle (taking into account fl ght and prefl ght power consumption, for example, fuel production, and losses, for example, aerodynamics) is less than 1 %, which is much worse than performance of the locomotive [1]. Herewith, all 100 % of energy spent on geospace rocket-based logistics actually destroys the planet ecology.

Plenty of disadvantages of the rocket are due to use of highly damaging rocket fuel (i.e., heptyl used for Russian Proton fueling is more toxic than cyanide), with ultrahigh temperatures of its burning and jet velocity, as well as required superpower of its rocket engines – about 1 mln kW for each ton of cargo. This is because reactive thrust of the rocket engines should exceed its combination weight, elsewise the rocket will not take off. Thus, fuel burning and cargo delivery to the orbit should take only several minutes, which requires high rate of acceleration and superpowers depending on thrust and speed.

In evidence of the above, over the course of rocket cosmonautics history, about 400–500 tons of cargo were delivered to the orbit (the average height is 300–400 km) per year. The same transport work on the Earth – delivery of 500 tons per year to the distance of 300 km – can be performed by one horse tackled up in a good wagon. And just as now one single wagon can't meet the transport needs of more than 7 bln peoples, so in future one single "cosmic wagon" will not be able to meet needs of space industry depending on needs of billions of earthlings, because such cargo flow will present only 0.1 g per a person a yea .

Thus, over the years, widely employed rocket geospace transport technology using thermochemical engines has reached the limit of its technological perfection but still has not become either environmentally-friendly, or economically available, or capable of providing a required cargo flow on geospace routes. That's why it cannot be considered for the future space exploration.

2.2.2 Non-Rocket Geospace Transport Technologies

Analysis of widely discussed issue of non-rocket geospace transport technologies such as space elevator, space cannon, space tower, and their variants shows the following.

A. Space Elevator and Its Options

The space elevator is the most widely considered and implementable non-rocket geospace transport technology. The concept was proposed in 1959 and developed in 1975 by Soviet engineer Yu. Arcutanov [2].

Cargo delivery to space and its reentry to Earth are performed with the use of the elevator with cargo which slides along the cable, with its centre of gravity being located upward the geostationary Earth orbit (35,786 km). Such position of the elevator gravity centre is provided by fastening a heavy balance-weight in the form of asteroid or large cosmic station on the higher orbit or by extending of the cable that it reweights its lower part. Matching of the balance-weight rotation rate and rate of Earth's rotation around its axis (daily rotation) provides geostationary state and allows to fix the elevator cable on the planet.

In addition to the common variant of space elevator on the cable stretched from the point on Earth surface to the balance-weight on the orbit in outer space, there are also variants of its upgrade with reduced weight of the entire structure. One of such variants involves raising of the cable fixing point to some man-made high-altitude platform (space tower or aerostat) that allows to cut both the cable length and its thickness along the whole distance. Another variant includes movable (by train, on shipboard, with the use of aerostat or even aircraft) base for fixing point of the space elevator cable, which will reduce the length of the cable thanks to the gain in circular velocity.

One of the hindrances for implementation of the space elevator project, including its improvements, is the lack of materials for the cable which should be of high tensile strength and lightweight. Its required material strength should be within the range of 65–120 GPa, considering that the tensile strength of the majority of heavy-tensile steels is only about 1 GPa. At present the strongest material is "carbon nanotubes" and their estimated strength should be more than 120 GPa, but in actual practice strength range of these fibers is 30–50 GPa, while their length doesn't exceed several metres [3].

Another critical obstacle for the project implementation is that construction of the space elevator should be performed from outer space. The cable should start at the station rotating at the geostationary orbit, with one end of the cable running down to Earth while unbending under action of gravity. The another end should run to the opposite direction to outer space while unbending under action of centrifugal force. This means, all the equipment of the space elevator containing millions of tons must be firs ly delivered to the geostationary station the traditional way, i.e., with the use of launch vehicles. But as it was stated above, rocket space industry is not able to perform this transportation task.

As per operational specifics of the space elevator, they are determined by the Coriolis forces acting on cargoes moving in the rotating system. The nature of these inertial forces refers to the fact that horizontal speed of the cargo lifted by the space elevator raises proportionally with the Earth rotation rate and the distance from the Earth centre while changing from 465 m/s near the Equator till the first cosmic velocity of 3.07 km/s at the geostationary orbit at the height of 35,786 km. Cargo lifted by the space elevator gets its impulse from Earth and the balance-weight rotating with the same angular speed through the cable stretched between them. As a result, the cable is under two heavy loads, i.e., the cable deadweight and two longitudinal reaction forces acting with different angles either side of the elevator cable and balancing Coriolis force that influences the ca go moving in the space elevator.

Presence of Coriolis forces stretching the cable which is under colossal stress due to its own deadweight disallow the space elevator to move at a very high speed. With reasonable estimated lifting speed of 100 m/s (360 km/h), cargo delivery to the geostationary orbit will take four full days. Herewith, the power required for the space elevator with a cabin mass of 10 tons and specified estimated lifting speed will be about 10 MW. It is just for one vehicle with a load capacity of only few tons and the same passenger capacity as a minibus provides. And what if the number of vehicles amounts to 100 or 1,000, how to increase efficienc in such case? Supply of such immense power will require to stretch power supply cables to the length of 36,000 km along the whole route from Earth to the geostationary orbit and establish thousands of the transformer substations per each 20–30 km which will be signifi antly heavier than the whole movable equipment, and the carrying cable will not withstand the load. Taking into account that the space elevator provides movement of the equipment up and down only sequentially, the annual cargo flow is estimated at the level no more than 5,000 tons. Therewith, the cargo circular space corresponds with the first cosmic velocity only at the height of the geostationary orbit. At the lower heights, the cargo circular speed will be always lower than the first cosmic velocity for the particular orbit, that's why the cargo abandoned at this level will fall to Earth. At the upper heights, the cargo circular speed will be larger than the firs cosmic velocity for this orbit and the cargo abandoned there will pass to outer space.

Geostationary nature of the space elevator, the cable of which is stretched through all the orbits used by the Earth rocket space industry, represents a source of risks of hitting the Earth itself by space rubbish having cosmic speeds and kinetic energies of great destruction power.

Therefore, the space elevator is a poorly developed geospace transport technology having a number of operating restrictions, including critical ones, and it is not able to provide a sufficien cargo flow on geospace routes. Hence, this apparatus can't be used for space industrialization.

B. Space Cannon and Its Options

The space cannon operates as an electromagnetic artillery tube or launcher accelerating a capsule with the space cargo in obliquity or vertically, respectively. The concept is to provide the space cargo with a relevant kinetic energy while avoiding need in fuel or other energy source on board in order to generate thrust force.

At the first glance, the space cannon is similar to well-known military cannon and looks like a non-rocket geospace transport technology near to implementation, but it is not quite the case.

The space cargo speeds should be about 10 km/s resulting in powerful impulse waves during its passing through dense atmosphere, signifi ant energy losses because of air pressure, as well as partly or fully burning of the cargo capsule cover.

Even if the cannon barrel length is 10 km, the cargo acceleration should be 5,000 m/s2 (500*g*), to provide it with the relevant space speed. Such over-extreme loads are unacceptable to the majority of cargos and that's why it is impossible to send spacemen in this manner.

In order to place the space cargo into the orbit, it is necessary to equip the cargo capsule with the traditional rocket engines to switch speed vector into rotational speed around the planet. Elsewise such space cargo will fall to Earth, including the other way around the planet, or pass away from Earth's gravity to outer space.

There are known concepts of space cannon (StarTram project [4]) with the barrel length of 1,500 km and the muzzle ring located at the height of 20 km. Such a long barrel tunnel allows reducing acceleration of the space cargo till acceptable 3*g* and it will become possible to send both cargos and spacemen to the orbit. Herewith, placement of the muzzle ring in stratosphere will eliminate threats regarding passing of the space cargo through lower dense atmosphere. But concept of this structure brings a number of new unsolved problems. How to keep this huge structure tilted? How to ensure strength of its large-diameter vacuum channel capable of withstanding colossal (especially near Earth's surface), compressive, as well as alternating aerodynamic loads during acceleration of the space cargo? How to power such a gigantic electromagnetic cannon held by an incredibly strong magnetic field with the relevant huge energies and at least equal strength currents?

Thereby, the space cannon as a geospace transport technology is also poorly developed and has a range of critical operating restrictions, as it is not able to provide a sufficien cargo flo , as well as does not perform redelivery of cargos from space to Earth, and that's why it can't be used for space exploration.

C. Space Tower and Its Options

Construction of the space tower with a height of 20–30 km is not an independent non-rocket geospace transport technology. The project of this astroengineering structure was proposed by the Canadian company of Thoth Technology Inc. [5]. Locating of launch platform at the abovementioned height (it is almost stratosphere) is only to improve indexes, i.e., to reduce weight, cost of the structure, energy consumption and increase carrying capacity of such geospace transport technologies, like traditional launch vehicles, space elevator or space cannon.

Regarding launch vehicles, it will be possible to opt out of the booster and reduce by about a third of power consumption, cut down environmental damage and increase carrying capacity. Regarding the space elevator on the cable, it will be possible to raise the lowest point of the space elevator fixation, cut down the length by 20 km (from more than 40,000 km), lightly reduce the whole weight of the construction and insignifi antly (by 0,1 %) shorten cargo delivery time and energy consumption. For the space cannon the longer barrel may be provided, which will enable reduction of power consumption and acceleration time and thus the loads on cargos during acceleration will be cut down, as well as place the cannon muzzle in stratosphere where atmosphere is heavy rarefied, so impact waves will be weaker, losses caused by air pressure and cover heating will be reduced, but vertical directivity of the space cargo impulse will heavily exacerbate the issue of its adjustment for arrival in the orbit.

Such tower consists of reinforced inflatable sections with the traditional vertical elevator inside of them. There is a start site for launching rockets at the top of the tower, where loading into the space elevator or nozzle of the space cannon is performed. To maintain dynamic stability of this structure, it is necessary to expend energy to feed the topping-up compressors, which is the main drawback of the space tower technology.

The present solution is technically unsupported by itself and can't be implemented because of known nonlinear dependence between the tower height and its cost, power, depth to the basements, issues of stability (seismicity and wind loads), and other feasibility issues; that is why there are still no structures on the planet which height exceeded at least 1 km, not to mention 20–30 km. Herewith, being a supplementary solution, the tower can improve operating capacities of launch vehicles, space elevator, and cannon. The space tower is not able to eliminate critical disadvantages of rocket and analysed non-rocket geospace transport technologies and therefore it is pointless to use it alone for space industrialization.

D. General Planetary Vehicle by Unitsky

The General Planetary Vehicle [6] is a ring encircling Earth along the equator with a transverse diameter of 2–3 m. There are gondolas with cargos and passengers attached on the outside of the GPV body. Belt flywheels are placed inside the body in vacuum channels; and they are driven with the help of magnetic bearings and linear electric engines in the direct and reversed directions.

The GPV operating principle is as follows: under action of centrifugal forces arising in the course of fast rotation (at cosmic velocities) of belt flywheels around the planet, the GPV body expands in diameter from equatorial size to required one, i.e., it pulls away from Earth and reaches the required orbit while lifting fastened cargo.

During launch, both the body and cargo fastened thereon are in the state of rest with respect to the Earth surface. In order to deliver the cargo to the orbit and leave there as a satellite, in the course of the body rising with the cargo, it is imparted with the first cosmic velocity relevant to the particular orbit, when centrifugal and gravity forces are balanced (weightless state). Boosting of the body with the cargo is performed through deceleration of one belt flywheel and acceleration of another one in the opposite direction (with respect to the first one) of motion (rotation around the planet). As a result, the body gets a double impulse and gains the required rotational speed. Thereon, transport work of the GPV on cargo lifting is completed and the cargo can be unfastened. The GPV transport work on space cargo return from the orbit is performed in the inversed order, i.e., space cargos are decelerated till the equatorial rotational speed while transferring their energy to the GPV belt fl -wheels, the body decreases across its diameter, and this way the space cargo is delivered to Earth.

The GPV operational principle is based solely on its internal forces and energy of the geospace transport system. Absence of any interaction with external environment provides the GPV efficienc coefficien near 100 %. Hereby, usage of environmentally friendly electric energy allows to maintain ecological safety. In addition, the energy of space cargos during their launch to Earth is imparted to belt flywheels, which turns the GPV into a global generator deriving electric energy on the principle of falling water in hydroelectric power stations. This operational feature of the GPV is of significant importance, because at the upcoming stages of space industrialization, the cargo flow from outer space will prevail and the GPV will generate energy instead of its consumption. Such high indices of the GPV energy efficienc allow, with its dead weight of 30 mln tons (750 kg/m), including 20 mln tons of the belt fl -wheels' weight, to provide load capacity of 10 mln tons (250 kg/m).

Hence, the General Planetary Vehicle designed by engineer A. Unitsky is a single geospace transport mean characterised by technical validity, unique energy efficien , and ecological cleanliness, as well as lack of operational restrictions to transport cargos and passengers enabling maintenance of industrial cargo flow in both directions of geospace route and workability for space industrialization.

2.3 Conclusions

Analysis of such geospace transport technology as launch vehicle has shown the following: despite it being a single and long-time used geospace transport technology, it can't be employed to solve geospace transport tasks of space industrial exploration. And attempt to increase a number of launch operations will not produce effect but accelerate occurrence of a global planetary ecological disaster.

Review of widely discussed non-rocket geospace transport technologies has proved their drawbacks excluding their employment to solve geospace industrial transport tasks. All found disadvantages of these non-rocket geospace transport technologies can be narrowed down to the following:

- they are not environmentally friendly technologies;
- they are poorly developed at least for the time being;
- they have operational restrictions, including critical ones;
- they provide low cargo capacity and low effectiveness

Thus, the single non-rocket geospace technology complying with all requirements of energy efficienc and ecological safety, able to successfully perform geospace industrial transport tasks, is the General Planetary Vehicle designed by engineer A. Unitsky. He developed the GPV project on the basis of nature laws more than 40 years ago, it was reviewed numerous times and tested by calculation methods that are specified in detail in various scientific publications and monographies by the author and investigations performed by a significant cadre of experts

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3

Creative Constructivism of EcoSpace Megasystem Design and Development: Engineering Creativity with Modern TRIZ – Reinventing and Perspectives

Techno civilization has been created by engineers. For several thousand years, millions of resourceful craftsmen, artisans, masters, engineers, and expert scientists have been upon the look for new ideas, building everything that surrounds us, producing and improving everything that exists in addition to what had been borne by nature.

At the same time, techno civilization is currently at the touch-and-go point of its uncontrollable growth. The problem is that inflicting irreparable damage to the nature in many ways. Consumeristic, greedy, wasteful utilisation of the world around us have come to the max limits beyond whereof it won't be able to restore itself and provide for the lives of the humans themselves.

Among the most dangerous sources of destruction are transport systems of all kinds, with exception of only, perhaps, bicycles. All these aspects have been convincingly analysed in the project substantiations of the need and opportunities for the development of the EcoSpace megasystem, the outstanding concept and constructive ideas of which were proposed as early as late 1970s, and first published in the early 1980s by engineer A. Unitsky [1–4]. The global mission of the EcoSpace megasystem, according to Unitsky, is to prevent the irreversible red line crossing by destructing nature and to build a new techno civilization as eco civilization which opens up new prospects for unlimited harmonious development of humanity.

Thus, an important task is to increase the efficienc of the EcoSpace systems and components design and implementation. Design efficienc includes acceleration and quality assurance of design solutions. Creating efficie solutions requires special skills in creative design by developers and managers. However, educational institutions do not offer academic programmes and methods for developing professional skills useful in generating effective ideas, especially in complex project situations with acute contradictions between requirements and resources available to achieve project goals.

The required quality, pace and reliability of training specialists in inventive systemically organised design thinking are provided, in aggregate, by the Modern TRIZ (MTRIZ) educational methodology and technology developed at the MTRIZ Academy founded by the author in the late 1990s in Berlin, Germany. Education and training programmes on the basics of MTRIZ [5–12] are essential and indispensable for all specialists, including top-level managers, in project and production activities when creating the EcoSpace megasystem.

The author has been supporting and sharing the ideas of engineer A. Unitsky for almost 25 years, and also brings to light in his works the EcoSpace megasystem's creative space through MTRIZ modelling [6–12]. In further development of this modelling, the present research, for the first time, formulates, at a higher qualitative level, generalization of the creative concepts of EcoSpace.

At the basis of efficien engineering ideas and solutions there is creative design thinking, which involves the ability and skill to mentally envisage the future function, design, or process. And only when the mental vision is transformed into sketch and drawing, into mathematical model, implemented in layout, technology and production and, finall , except for recycling, in use and operation.

For the first time in the history of civilization (and in the history of engineering creation), the TRIZ – Theory of Inventive Problem Solving – revealed the design principles and patterns of creative thinking, offered creative tools – methods, models, and examples – for efficien inventive design thinking [13–15]. Along with engineering knowledge, the knowledge about the creative space of the engineer's thinking was developed. The TRIZ principles (yet without this name) were first published in 1956 and 1962 [13, 14] by the founder G. Altshuller (1926–1998), and until the mid-1990s the TRIZ has been evolving under his leadership [15].

By the mid-1990s, the basic MTRIZ principles were shaped in the form of new structures and procedures (extraction, reinventing, Meta-Algorithm of Invention T-R-I-Z, etc.) in order to efficientl master and apply the TRIZ fundamentals. A de facto "constructive language" was created to present information about the process of invention, accumulation and transfer of inventive experience and solutions, the language of communication in multidisciplinary creative teams (Think Tank Teams).

During training, the TRIZ methods and models (MTRIZ) provide explanation as to the process of birthing ideas, whereas in post-training, they become thinking navigators for creating efficient ideas in new problem design situation

EcoSpace megasystem creative ideas can also be efficientl interpreted in terms of the MTRIZ concept system. This interpretation will help developers to comprehend more profoundly creative constructivism which constitutes the creative core of the engineering and social transformations being developed in the EcoSpace projects. For the sake of brevity, we will consider examples on two key EcoSpace systems – UST and SpaceWay (although, undoubtedly, all EcoSpace projects have outstanding properties and characteristics and correspond to the models and generalizations under consideration).

The fundamental metaphorical the TRIZ principle, which sets the vector of development and evolution of systems, is, according to the author's interpretation, the Ideal System Maxim: there is a function, but there is "no" system for implementing thereof. Two creative trend aspects are as follows:

- there is no habitual system for obtaining the desired function;
- the function is created by other (surrounding) systems, or its implementation has shifted to another level – higher or lower one.

The value of the metaphor is to eliminate the retarding stereotype of habitual thinking, to set an "impossible" goal. Let's reveal (extract) internal creative "catalysts" of the basic string concept – UST.

What are the development limitations of traditional roads? They are not straight, they are cumbersome in design, energy- and resource-consuming, environmentally unfriendly, and therefore costly for humanity. As a result, they are simply "slow" and have no development prospects in principle (they are penalized in development). All traditional roads are alike that, anything from a rural earthy track to a ultra modern maglev-complex. Could a similar "road" be built with all such defects disappearing?

It was that "ideal road", "ideal system" that was invented by A. Unitsky in the form of the string concept underlying the UST projects.

Five technological revolutions are the markers of the "Road" technical system evolution increasing speed and cargo efficienc

1st revolution (6,000 years ago, the Sumerian state in Mesopotamia): the invention of the wheel – wooden, then iron, and so on;

2nd revolution (5,000 years ago, Egypt; 4,000 years ago, Europe): the invention of the pair "wheel – artificial road" (wooden, stone)

3rd revolution (500 years ago, the mines of England, Ireland, Russia): the invention of the pair "cast iron wheel – cast iron rail";

4th revolution (160 years ago, R. Thomson): the invention of the pair "pneumatic wheel – road" (earthen, stone, concrete, etc.);

5th revolution (30 years ago – end of the 1970s, A. Unitsky): the invention of the pair "steel wheel – steel string rail".

A. Unitsky invented a fundamentally new road that is elevated above the ground (UST), which corresponds to the TRIZ model "Transition to another dimension", with the ability to connect start and arrival points in a straight line (consistent with the models "Change of aggregate state", "Replacing mechanical environment", "Use of composite materials" and "Mediator"). Of course, the old principle of the road to achieve higher speeds and improve capability no longer exists.

The string-rail (prestressed) road is surprising, innovative and bold approach, according to the TRIZ, with outstanding system-forming wow-eff cts: creation of ecologically friendly residences for the users of such roads, rational use and purification of the land, which altogether guarantees safety and comfort

In the same vein, we can consider A. Unitsky's string rail idea as "challenging" the concept of classic monolithic (solid) rail, even just by being used in various variants of monorail elevated roads.

The rigorous problem of the railway pair "steel wheel – steel string rail" consists in the fact that the rail has a small deflection radius, and therefore the railway wheel does not roll along the "perfectly" smooth track, but "digs itself out of the hollow spots" all the time – out of the bent rail. And same is true for all tens or hundreds of wheels of a heavy train (of concentrated load). Colossal energy is spent on overcoming continuous resistance.

The "smart" string rail (in accordance with the TRIZ model "Matryoshka") has a core made of tens and hundreds of wires, each stretched as a string, and all together – as a single powerful and perfectly straight "super-string". Here it is – the Ideal System Maxim: the function of the "ideal" road, but there is no usual rail. A new "ideal" system rail has been invented.

Now let's pay attention to the fact that there is another creative TRIZ metaphor in the interpretation of the MTRIZ – the Ideal Change Maxim: "there are no changes", but there is result. Another expression for this maxim is: get the result "without changing anything"!

Indeed, outwardly the string rail looks quite "solid" and "monolithic", and therefore it seems that it has not far gone from the classical monolithic rail from the point of view of the deflection radius, since there are no significant changes, except for the external form. However, this is not true: the string rail is a fundamentally new technical system. Thus, there are (almost) no external changes, but there is a new function!

Further, an extremely important system MTRIZ defi ition "The Ultimate System" is implemented here: the principle of such system cannot be surpassed, it is the best in the class of all systems of this type. The string road principle cannot be improved on the totality of properties in the class-concept of the "Road" as mechanical transport system based on the system invariant of this class – the "wheel – rail" pair.

It is important to note that the string rail becomes a system invariant of many transport projects, giving the name to the "string transport systems" class, including UST, Umach, SpaceWay. Creative design of these systems is covered by the above concepts by analogy with the UST string structure-based example. In turn, all these systems, together with the string concept, are the system invariant core of complex systems GreenWay, EcoEnergy, and EcoSpace.

To elaborate the study of creative constructivism in EcoSpace systems, let us show the presence of key system and creative concepts, invariants and models in the General Planetary Vehicle (GPV), the idea of which was proposed by engineer A. Unitsky in the late 1970s, and first published in 1982 [1]

First of all, the GPV is an "Ultimate System" – its general idea and physic-technical principles (acceleration, ascent into near space, manoeuvring, presence in space, returning to Earth), as well as the principles of structural transformations during operation (telescopic structures, stretching and compression of materials) are one-of-a-kind for self-supporting geospatial aircraft with zero need in fulcrum point (the "Baron Munchausen" principle). A. Unitsky's inventions create constructive engineering and creative paradigm for the implementation of the aspirations of Russian cosmism and therefore open a new history of the Earth, more precisely, geocosmic civilization.

In the GPV, the Ideal System Maxim is implemented: a linear (belt) rotor, spun in a vacuum channel to a speed exceeding the Earth orbital velocity, acquires the ability to independently rise into space without losing stability – it will be stretched all the time like a ring string.

The presence of the Ideal Change Maxim plays an important role in the GPV functioning: the elongation of the circumference of the ring structure (rotors and body) during and after ascent to specified orbit makes up a small fraction of its length on the launch structure. So, when the rotor expands from the diameter (broadly speaking) of 12,700 km with a starting circumference of about 40,000 km in length, to the orbit diameter, for example, of 13,100 km (i.e., with an orbit "altitude" of 200 km above the Earth's surface) and the orbit (and hence the rotor) length of 41,100 km, the relative elongation of the rotor will be 2.75 %. From which it can concluded that such elongation can be ensured even at the expense of safe elastic stretching of the rotor material and is quite reliably feasible when using controlled telescopic structures.

The number of instrumental creative models in the GPV idea includes almost all the classical TRIZ models. Here we indicate the most important, dominant models in the most simplified illustrative interpretation

- "Change in the aggregate state of object" – stretching and compression of the system components of the structure;
- "Replacing mechanical environment" – string structure of the main structures;
- "Dynamization" and "On the contrary" – acceleration for take-off and braking for rotor landing;
- "Copying" – rotor self-stabilization according to the principle of a spun lasso;
- "Periodic action" – possibility of take-off and landing
- "Mediator" – the rotor lifts the cargo;
- "Transition to another dimension" – the rotor spins up in a plane (2D system), and rises and falls in height (3D system);
- "Antiweight" – centripetal forces lift the GPV;
- "Matryoshka" – the take-off and landing system and the rotor system with the shell are nested structures.

Such examples can serve as efficien educational content for the EcoSpace designers.

Finally, let us pay attention to the fact that the ideas of EcoSpace complexes exactly correspond to one more MTRIZ system definition of the Eternal System: a human-technical system exhibiting unlimited life expectancy thanks to the ability for self-preservation, self-restoration, self-renewal, and self-development. It is easy to see that GreenWay, EcoEnergy, and EcoSpace complexes have all the features that meet the definition of the Eternal System

It should be noted that the above does not necessarily mean that all previous generations of technical systems "become obsolete" (some of them will indeed be dismantled and cancelled), most of them will move to another status, while remaining in more appropriate niches of application.

The given examples of the study of system properties arising from A. Unitsky's inventive ideas and constituting the creative core of all EcoSpace projects reveal the leading creative concepts of the internal creative space of the EcoSpace megasystem. These concepts are related to the level of engineering philosophy and philosophy of creativity in general. At the same time, we actually carried out the "reinventing" of A. Unitsky's ideas at this level.

At the same time, the methods and models of the "instrumental" level can and should contribute to the actual project work. To tackle the majority of everyday tasks, it is sufficient to possess methodological knowledge and ability to use the tools presented in the author's basic books [5–7, 10].

The technology of training and practical work in the MTRIZ is based on two methods:

- extracting (identification and retrieval of efficien creative models from previously made innovations and inventions);
- reinventing (modelling and reproducing the complete idea creation process in such a way as if this invention was made using the TRIZ models).

It is this way of presenting knowledge in the MTRIZ which makes it possible to model and study the logical structure and procedural components of the invention process.

To standardize the presentation of information, an "ultimate" Meta-Algorithm of Invention T-R-I-Z has been proposed. It is a methodical scheme for describing transformations and reinventing results, consisting of four functional stages: Trend (goal setting) – Reduction (formulating contradictions) – Inventing (searching for ideas) – Zooming (analysis of ideas at different scales). The first letters of the titles of the stages make up the T-R-I-Z abbreviation in the form of the name of the meta-algorithm.

Since all the examples of the MTRIZ modelling and all the processes of creating new solutions follow the T-R-I-Z meta-algorithm, this provides a de facto standardized format for presenting information, which drastically simplifies the learning process, becomes a simple structural format for documenting reinventings and inventings (new solutions), an understandable communication language in multidisciplinary decision finding groups (Think Tank Teams), an efficien base object for accumulating creative project experience and transferring this experience between company units and work groups.

Therefore, the author is convinced that mastering the MTRIZ basics very likely to be an efficien and even indispensable component of project activities, worthy of integration into the EcoSpace megasystem creation process.

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4

Key Aspects of Project and Construction Management of Astroengineering Systems

4.1 Readiness of Modern Digital Technologies for Development and Manufacturing of Astroengineering Structures

Over the last ten years, there have been a new wave of interest in space exploration, accompanied by expanding boundaries of the explored activities and transition to innovative space technologies, which aim to increase efficiency and safety of humanity. In order to achieve sustainable development on Earth and in space, it is necessary to reach a new level of space exploration through creation and implementation of global strategy. The primary goal of any project included in such strategy will be the survival of civilization and its development, protection of Earth and formation of cosmic humanity.

There is a signifi ant potential for the formation of a new technological structure by means of transition to environmentally friendly technologies and projects, many of which have been developed for a long time and now they are ready for practical implementation [1]. One of such technologies, related to the category of non-rocket space exploration, is the General Planetary Vehicle (GPV). Its main purpose is to launch cargo and passengers on different circular equatorial orbits. The technology uses the only possible technical solution which is environmentally friendly method of reaching into space – process of its functioning has limited interactions with the environment (energetic, mechanical, chemical, and other types) [2].

As a geocosmic vehicle, the GVP is a giant astroengineering construction in the form of a stable self-supporting structure, the building of which will require fusion of the most advanced ideas and technologies currently available, as well as all of humankind's accumulated knowledge and skills in space exploration.

The purpose of this research is to find the answer to the question: "Are the innovative technologies ready for the implementation of planetary-scale astroengineering structures?" The research on the topic requires in-depth study of the design and production tools, the necessary competencies of engineers and workers and their level of interaction at the confluence of different discipline

The GPV consists of many elements, such as Equatorial Linear Cities (ELC), including launch pads for the GPV; Industrial Space Necklace "Orbit" (ISN "Orbit"); biospheric EcoCosmoHouses (ECH). Each element technologically will combine the majority of the existing systems and technologies: mechanical, control, communications, life support, security, power, energy, hydraulic, pneumatic, biological, computer, and many others.

The creation of astroengineering structures is an ambitious task for humanity. It requires the unification of almost all of the modern design and production tools, considering the entire life cycle of such systems. It is necessary to develop the understanding of the current approaches to design, production, and development of new methods with more systematicity, transparency and digital data connectivity. In addition, a large number of specialists involved in different disciplines and from different countries should be interconnected. Relevant working conditions should be organised to ensure efficienc of those joint efforts. To accomplish this task, it is necessary to use sufficien computational power. Virtual systems will be used for conducting virtual experiments on the elements of the GPV and its subsystems.

To implement large-scale engineering structure, it is required to develop integrated architecture of its systems. Such architecture should have high level of functional security and it should connect all subsystems, their operational parameters and dependencies of hundreds of thousands of connecting factors. For example, a modern passenger car has about 300,000 requirements, separated in individual specifi ations for various systems and subsystems. Moreover, it would be necessary to create methodology of converting uncertainty in requirements, solutions and system architectures into understandable tasks and precise parameters that affec the behaviour of various systems in different situations. In order to accomplish this task, it is necessary to modify the approaches of system engineering simulations and modelling. Digital twins of products and systems, that are part of the astroengineering structures, should have the detailing level that ensures accuracy and scale 1:1 for the subsequent manufacturing. In addition to the multiple calculations, a large number of virtual experiments and results validations will be required in the process of developing astroengineering structures and necessary systems. For these purposes, software solutions and associated hardware platforms will utilise nearly all of their capabilities. As, in case of most systems, it will be impossible to create a prototype with the real dimensions of the system, the project design flow will require

significantly higher amount of virtual experiments and simulations, in comparison with the current construction projects.

Development and construction of the astroengineering structures is a worldwide project. Implementation activities will require precise coordination of activities of the companies, involved in the manufacturing process, including suppliers and manufacturers from various locations around the globe. Thus, the project implementation processes will be conducted in parallel: product development, production and construction. Furthermore, optimisation of the design and technological parameters will play a significant role. Design optimisation should be completed for various characteristics, such as weight, energy, strength, materials science, operational, financial, and other technical and economic characteristics

Design process for a set of products was revolutionised with the global shift towards automation, computerization, integration of cyber-physical systems, embedded in the production processes and its components. Moreover, there are solutions to establish tight links, which connect processes of creation, manufacturing and operation of the developed systems. At the same time, new products have increased complexity and improved quality combined with the needs to reduce their release and market launch times. The key factor of the fourth industrial revolution (Industry 4.0) is the combination of digital and mechatronic technologies, applied to the development and production processes. The combination of scientific disciplines, technologies, and innovations as a result of their interaction becomes possible mostly due to the continuous increase in the speed of data transmission and usage of digital tools for joint and remote activities. Nowadays, companies and countries take part in collective innovations by creating environments for joint functioning at the intersection of technologies which leads to the acceleration of the market launches of the products across all areas. Simultaneously, the opportunities are provided for continuous improvement and updating of both development and production methods, which leads to the creation of completely new products. For example, it is possible to combine additive technologies, material engineering and synthetic biology [3].

Digital platforms for product lifecycle management (PLM) represent a complex digital system, which is made up of subsystems with individual tools, that affect di - ferent aspects of development, design, verification, production, operation, disposal and optimisation of engineering solutions at all stages of the product's life cycle. This system interacts with the unified recent information in real time. It allows different participants of the product creation to track all applied changes in the related areas, identify possible collisions and eliminate errors before the start of the production.

Today's PLM platform can include several thousand of special modules. For the astroengineering structures construction, the following elements should be included:

- **CAD** – computer-aided automated design tools to generate 3D models or 2D drawing of physical components;
- **CAE** – computer-aided tools for automation of the engineering calculations, analysis, and simulation of the physical processes;

- **CAM** – tools for technological preparation of the production of the components, it provides automation of programming and management of the numerically controlled equipment or flexible automated production systems
- **CAPP** – tools for automation of the technological processes, which are used at the joints of the CAD and CAM systems;
- **PM** – project management systems;
- **PDM** – system for product data management;
- **WMS** – warehouse management system;
- **CMMS** – system for service maintenance management;
- **CSRM** – management of the interactions with the clients and suppliers;
- **MES** – special applied software solution to monitor and manage tasks, related to synchronization, coordination, analysis, and optimisation of the output of manufacturing within the frameworks of any production line;
- **MOM** – production process or operations management;
- **ERP** – planning of the resources of the enterprise;
- **BIM** – information modelling (or model) of a building;
- **MBSE** – model-centred approach to systems engineering;
- **MDB** – non-drawing technology, containing annotations and markup not in a 2D drawing, but immediately on a 3D model;
- **VR, AR** – technologies of virtual and augmented realities, designed to create a virtual scene, based on a 3D layout and dynamic data using special glasses that simulate stereoscopic behaviour for a person. AR allows developers to complement the picture from the real world with the elements of virtualization;
- **IIoT** – Industrial Internet of Things, the technology of creating cyber-physical objects by embedding computers into actuators, individual devices and entire industrial lines, allowing to build all the elements into a single system, suitable for both production and operation. One of the developmental branches of IIoT is the development of crypto-anchors;
- **Digital twin, digital Shadow** – creation of a digital twin of the product and a digital shadow of the manufacturing process, simulation of all stages of production, taking into account the behaviour of equipment and tooling [4].

Today, there are three global developers of the design platforms for the needs of Industry 4.0 on the world market, which allow uniting an unlimited number of participants to build any products and systems: Dassault Systèmes offers the leading industry applications, which are based on the 3DExperience platform; Siemens – PLM Software off rs its own solutions, which are based on Siemens PLM platform; and PTC Inc. developed a platform, based on the PTC platform.

The combination of the described PLM modules working together allows to implement high-quality digital twins both at the stages of design and product development, and at the stage of early results verificat on. Modules, included in the PLM platforms, e.g., high-level CAD like CATIA from Dassault Systèmes, allow to create digital twins of the objects of increased complexity, such as the GPV or ISN "Orbit" in natural scale with necessary engineering accuracy

along the whole length (for example, for the GPV is it exceeding 40,000 km) of the objects without abruption. Digital 3D model of the system should include: terrain relief, foundations, supports, design of the overpasses and the GPV. In addition, the PLM platform allows to combine engineers and applied specialists in the simultaneous development process, while related documentation is centrally managed with the process of keeping all versions and revisions of changes in conjunction with the project objectives. This approach makes it possible to identify all inconsistencies and deviations of different project areas and systems. Nowadays, there are examples of digital twins, created for the complex systems uniting few million items. For example, Harmony of the Seas, which is a cruise ship from the class Oasis, was modelled in the PLM platform 3DExperience with the total number of parts about 50 mln.

Another serious problem to be solved during creation of the astroengineering structures is reduction in the number of errors during design and production. For a large scale system, even minor errors can lead to the serious consequences. Therefore, system engineering approach will play an important role. Traditional approaches of systems engineering [5], being good enough, leave enough room for errors. One example of the "collapse of the classical approach" is the NASA Mars Climate Orbiter, which was launched on December 11, 1998. After nine months of flight, it crashed on the surface of Mars due to the software having been developed by two different groups of developers, who used different units of measurement: newton and pound-force [6].

Figure 1 demonstrates an example of differences in quality of the product, which was manufactured using the "old" (document based) and advanced (data-centred) approaches to system engineering. Data-centred approach was completed using the MBSE method (based on combination of the digital technologies).

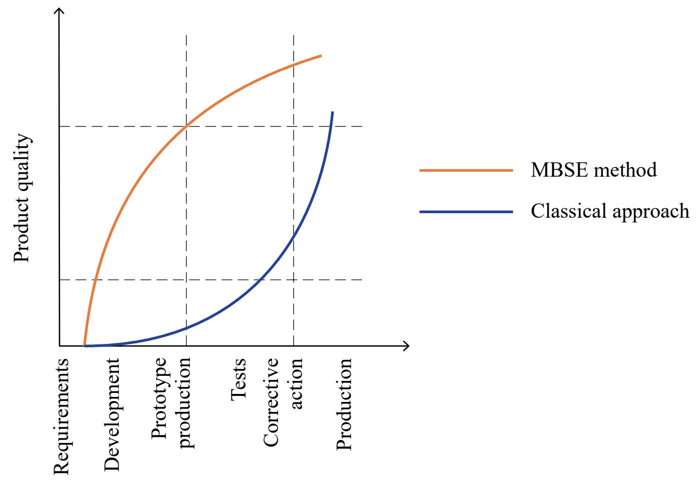

Figure 1 – Standard and advanced approaches to system engineering

Development of comprehensive links between 3D digital twin and the product itself is the key element of the advanced model-centred approach [7]. It is important to analyse system's performance with the changing conditions and variable inputs from the early stages of the development of the system. To achieve those tasks, a set of activities can be used, including simulation tests, simulation modeling in virtual reality, analysis of the key systems using the generation of anomalies, robustness of systems, analysis of intersections and systems' conflicts, etc. Collected results allow to eliminate errors, carry out multidisciplinary optimisation of the processes, individual elements or the entire system, confirm satisfaction with all the requirements. This approach significantly improves the processing of errors and the maturity of the product at the pre-production stages. Furthermore, it reduces the influenc of so-called "human factor".

Primary role of the MBSE methods is to improve quality of developed products and achieve reduction in number of errors. Consequently, this method can be used in the creation of astroengineering structure in two way – in development of the subsystems and their analysis and for the integration of the structures in the existing environment. For example, the GPV operation should be synchronized with the air traffi control procedures and with the monitoring systems of submarines and ships around the world. These approaches have been already widely used in the development of aviation and space systems and programs.

Simulation modeling is an important part of digital systems engineering. It is a research method in which the system under study is replaced with a model that represents this system with high accuracy. Constructed model acts upon the given inputs of the processes in exact same way, as the real system would act, including nonideality of the processes and systems. Such model can be a "play back" in time both for a single test or for the given set of changes, as a result allowing to receive fairly trustworthy data. Today, the convergence of results in the virtual and real worlds can be as high as 96 %. Zero-prototyping is the key achieved process based on the high accuracy of models approximation – safety certifi ation can be done without real crash tests of the vehicles (used by BMW AG, Honda Motor Co.). Usage of the PLM tools allows to implement an integrated approach to studying the behaviour of the products and systems under development. In particular, the 3D digital twin, which incorporates all systems of the product – mechanical, hydraulics, pneumatics, electronics, etc., is studied within the simulation environment. As a result, the entire systems performance can be observed including interactions with differen surrounding environments and behaviour of materials in dynamic conditions. The use of VR may allow a deeper and more comprehensive study of the behaviour of components and assemblies of the created products, for example, a passenger gondola or elements of linear electric motor of the GPV.

The next level of simulation includes establishment of the connection between the digital models of the physical environment and actuators and their 3D models and controllers or control computers, which are processing digital data. Based on this approach, leading automotive companies like Tesla, BMW, Renault, and others, conduct debugging of the control systems in virtual space using real controllers.

It allows to find out the best algorithms and to eliminate errors for systems such as AEBS, mechatronics, electrical power plants at early stages of their development. After the data-based training is completed, a series of finishing works can be conducted with actuating mechanism under the conditions of a real environment. The same principle allows to train neural networks in the virtual space and then transfer the developed control system to the hardware. A similar level of simulation can be used in the flight control centres to simulate the control of the GPV in different situations, taking into account thousands of events at any point and with any system. In addition, it will provide an opportunity to implement different algorithms of system's performance.

Simulation modeling plays very important role in the development of astroengineering structures, as it allows, in conjunction with digital twins and system engineering, to debug control algorithms with high accuracy, in conjunction with digital actuators. It should be done to imitate the ways of functioning of the GPV systems on Earth and create thousands of take-off and landing procedures. It will lead to identifi ation of the weaknesses of real industrial controllers, running the GPV. The procedure will also imitate various events and improve the responses and performance of the GPV utilising combination of software-hardware models. Moreover, it is possible to approximate the behaviour of ECH system in the space and for various scenarios. It will allow to study combinations of security and life support systems to develop appropriate actions for regular and abnormal cases.

All the above-described tools of the Industry 4.0 concept (CAD, CAE, CAM, WMS, MES, MBSE, simulation modeling, etc.) also find their application for production and construction purposes.

Digital production, with the technologies like IIoT, AR, Big Data, digital shadow and planning systems, allows to analyse production power requirements and balance resources taking into account the separation of production sites. Such control systems will be used to prepare interconnected manufacturing and construction schedules. The requirements of such process come from the idea, that the work will be done by various parties in different locations, but their action to complete the GPV, should be synchronized.

If we consider end-to-end processes from development and design to production and construction, it can be noted that the quality of the resulting product depends on the maturity of the process at all stages of the life cycle. In the classic version today, there are five levels of the maturity of the processes (able).

Astroengineering structure project will require to lift the maturity of the included processes to the highest, fif h, level and, further on, form a level exceeding the current 5^{th} (level 5+). In return, it will require to increase the digital connectivity of the system elements, qualifications and level of interaction of the employ es and stakeholders.

It is also worth noting the important role of additive technologies and generative design for the space industrialization process [8]. They allow to reduce the production time of the structural elements of the GPV, further analytical work can optimise the mass-dimensional characteristics of elements of ISN "Orbit" and explore the uses of space materials (minerals from asteroids, space debris). Finally, it will be

Table – Maturity levels of CMMI processes

Value	Level 1 (basic)	Level 2	Lever 3	Level 4	Level 5 (world leaders)	Level 5+
Name of the level	Starting	Repeated	Standardized	Measurable	Optimisable	
Necessity to redo, %	40	20	10	6	3	< 3
Forecast tolerance, %	30–100	10–20	5	3	1	< 1
Reducing the likelihood of defects in the end product	*x*	1/2*x*	1/4*x*	1/10*x*	1/100*x*	1/1,000*x*
Early detection of defects, %	< 30	60	80	90	99	99.9
Performance, %	100	150	200	350	> 400	
Repeated use, %	Insignifican	Insignifican	Accidental	> 30	> 50	

easier to facilitate the production of necessary tools and parts without deterioration of the mechanical properties.

All of the above technologies are powerful tools of progress in almost all areas of modern life. They contribute to accelerating the process of diffusion of technologies and innovations, which leads to their accelerated creation: starting from digital collaborative development tools, system engineering, and simulation modeling and ending with collaborative innovations.

Creation of the breakthrough technologies and increased market competition are the consequences of the accelerated information exchange processes between development teams of the same project and between engineers and customers. New approaches are rapidly being duplicated and implemented throughout the world. These processes crowd out old business models and products. In addition, there is a drop in the cost of technologies, which makes them more afford ble. All of these elements lead to the stronger competition in the creation of advanced, more improved ways of production and approaches to the product development, as well as more advanced products and systems architectures. For example, the cost of 3D printing of the same part decreased from 40,000 USD in 2007 to 100 USD in 2014. Also, the cost of 1 kWh of solar energy in 1984 was 30 USD, but reached only 0.16 USD by 2014 [8]. Thus, the diffus on of technology and innovation contributes to cost reduction and simplified access to technology [9]

This paper reviewed modern digital technologies, their potential in case of their application in the project of building of astroengineering structures with some examples. Many problems, which seemed intractable to engineers and designers 20–30 years ago, are currently seen as tasks of varying degrees of complexity. The main limitation of the modern digital design tools is the computational power.

This hurdle can be solved by using industrial mainframe computers, which can be, for example, rented or remotely accessed. Digitalisation of processes, acceleration of diffusion of technologies and innovations leave no doubt that humankind today has all capabilities to begin the development and production of astroengineering facilities. Project, which is necessary for the survival and sustainable development of modern technocratic civilization.

4.2 Special Aspects of Management Methods for Design of EcoCosmoHouse on Planet Earth

EcoCosmoHouse on Planet Earth (ECH-Earth) is a multipurpose construction facility, which requires inclusion of various functions [2]. During the implementation process, it is necessary to take into account a wide number of requirements in various areas, such as ecology, economy, and construction standards while meeting the key aim of creation of the enclosed ecosystem. Another significant feature of this project is possibility to initiate its operation in two phases. The first phase includes a profitable hotel business with an enclosed recreational area. The second phase is based on scientific studies of a closed biosphere as an analogue of a cosmic settlement. ECH-Earth is only a small part of the global program of space industrialization, covering the General Planetary Vehicle, the Equatorial Linear City, and the Industrial Space Necklace "Orbit". The latter system includes biospheric EcoCosmoHouses, the model of which will be implemented in ECH-Earth [2]. One of the main aim is to realise the project within the Earth environment, to create a self-contained, independent, and isolated biosphere, which seems to be a non-trivial construction and design task. Implemented analogues do not exist anywhere around the world.

According to the regulatory documents, ECH-Earth belongs to the first class of construction complexity (K-1: 5.1.2 Large-span buildings and structures with spans over 100 m and clause 5.1.20 Buildings and structures, the design and construction of which requires the development of Project Specific Technical Specification – PSTS) [10]. PSTS is a document containing technical standards developed for a specific capital construction facility. If during the design of different facilities types it is impossible to comply with all required standards established by the legislation, or if the regulatory documents do not establish requirements for the particular type of facilities, PSTS should be developed separately to take into account required construction features.

Based on the discussion above, it is extremely important to choose the optimal method of project management before starting the design processes. Any project consists of a set of processes – initial conditions, requirements, achievements of the expected results and milestones, phases, stages, sequences of processes, tasks, operations. Each process has start and end dates and they should be combined in a single system. The reference points of the project are called milestones, which

help to track the achievement of the intermediate results. Project's objectives can be considered as achieved once the results meet specifi pre-stated requirements. In the course of the project implementation, it is necessary to monitor continuously the assigned tasks for their completion and compliance of the achieved results with the requirements of the customers. At certain milestones, assessment process is completed to evaluate the depth and degree of completeness of the tasks and the compliance of the results with the established requirements. If necessary, the subsequent plan can be adjusted, as an outcome of the milestone review.

Project management methods have their pros and cons. The choice of method and its application depends on the client's expectations, the type and content of the project [11]. The importance of competent selection of the management approach can be realised by studying world experience and observing the successes and failures of large-scale programs. For example, 400,000 NASA employees and 20,000 companies and universities participated in the implementation of the Apollo mission. The ambitious goal was set as landing a man on Earth's satellite and returning them back. It required an incredible amount of resources, cooperation, innovation, and planning. The task of managing this project was assigned to Dr. J. Muller. His key decision was to divide the project into several parts, which made it easier and more efficie to control specific elements of the project, rather than the entire system design. Developed system showed its efficienc and the project was completed ahead of the provisional schedule [12].

For completeness of the analysis, the author of this paper investigated the world experience of project management in various field . The following methods and modes of management were analysed: Adaptive Project Framework, Benefit Realisation – BF, Agile, Critical chain project management, Critical path method, Kanban, Lean, PRISM, Process-Based Project Management – PBPM, Scrum, Waterfall, etc.

After the completion of the research, the main methodologies were chosen using the parameters, which are suitable for the successful implementation of the ECH-Earth project.

Agile. It is a flexible methodology, the key parameters of which are resources, team building, teamwork, cooperation, and the search for compromises between employees. An additional important advantage of this methodology is that participants in the design process quickly make adjustments and produce a result. Agile encourages participants in the process to be focused on a specific task and eliminate temporary losses from work that are not related to the problem being solved. It helps to maximize efficienc of collaboration. Documentation in this approach has the second priority. Meanwhile, the key priority is to find a working solution and check the compliance of it with the requirements [13].

Critical chain project management. This approach is based on the formation of key tasks with the final date of completion of the project. Logical links built between tasks take into account possible limitations of temporary reserve funds. In other words, this method determines a certain critical path (sequence of tasks) with certain deadlines which, if violated, are compensated for by the time buff r allocated for unforeseen circumstances and planned in advance (a risk management mechanism is introduced). The main task of the critical chain project management is to create conditions for intensive work, to increase the team's efficienc by eliminating safety reserves of time in individual tasks. The method enhances the pay-off of the team, feedback and directs participants towards a single result [14].

Kanban. Its distinguishing feature is the visualisation of a constant flow of tasks, which helps to identify challenging points. It allows to quickly responding and paying attention to the tasks that are underperforming [15].

PRISM. Methodology focused on the so-called "green" facilities with the aim to reduce the negative social and environmental consequences from the project activities. PRISM allows for rational use of tangible and intangible resources, intelligent allocation of natural resources. It also takes into account factors that have direct or indirect environmental impact [16].

Scrum. A method is based on the teamwork and problem-solving activities within fixed time intervals, which are called sprints. The purpose of each sprint is to solve the given problem. Iterations is the backbone of the project development process in Scrum. The following rules are typical for Scrum: planning and managing a list of requirements; iterations planning; interaction between members of the project team; analysis and adjustment of the development process. In this methodology, the role of a leader is very important, and the roles of each team member are clearly defined. Moreover, each of the participants have several roles. Most often, Scrum team includes about seven people. The team determines by themselves how to solve particular problem. The methodology allows setting clear tasks that have a definite final goal. Scrum is more focused on the product development process, rather than on the management process, and can complement another management process [17].

Waterfall. It is a cascading planning model in which tasks follow each other. Completion of a task or several processes usually means that a milestone is achieved. In this methodology, activity progress charts (Gant charts) [18] are used to monitor execution.

An important factor for successful project management is the use of suitable software that allow, in conjunction with the chosen methodology, to control the design process. ENOVIA Program Management – a product of the 3DExperience platform from Dassault Systèmes – was chosen for the research as an example of software containing the necessary functionality [19]. ENOVIA Program Management helps to solve the following tasks: project initiation, its planning, execution, monitoring and control of assigned tasks and project closure. This platform is connected with the main software products such as MS Office, MS Project, etc. Combination of these elements allows to quickly navigating through the project structure and quickly responding to various changes (setting tasks for performers, tracking resources, tracking and adjusting the schedule, storage, and availability for the execution of the necessary information). Furthermore, the platform allows connecting new participants from any device anywhere around the world, if the technical capabilities and legal agreements are available presented.

The study showed that under the condition of the multi-vector uncertainty of the various parameters of the ECH-Earth facility and its multitasking, the use of a single, long-known methodology may be ineffective. Multitasking dictates specific design management rules. Due to the fact that the tasks in the project have multidisciplinary nature and have different indicators, such as specifics, deadlines, complexities, required resource, and other criteria, for eff ctive management of this project it is necessary to focus on the key advantages of the selected methodologies. To be more specific, the following allocation can be used: Agile and Scrum to be used for resources and their interaction, Kanban – a visual component of tracking results, PRISM – environmental aspects in the design, Waterfall – for certain tasks and tracking the entire design structure. It is also important to modify the system, introducing or adjusting used methods and approaches. The software applied to manage the design should be focused on a specific element of the project, be fle ible in terms of management approach, and, also, have a convenient user interface (usability). The software product should assist to track critical milestones in order to respond accordingly. Appropriate response to the emerging problems can be achieved if the following steps are taken: competent choice of methodologies, according to their key values, software selection, qualified specialists, and a clear understanding of the main goal. Competent selection of the methods to address these tasks will have a positive contribution on the design process of ECH-Earth as well as on the global projects, which are required for further large-scale space exploration.

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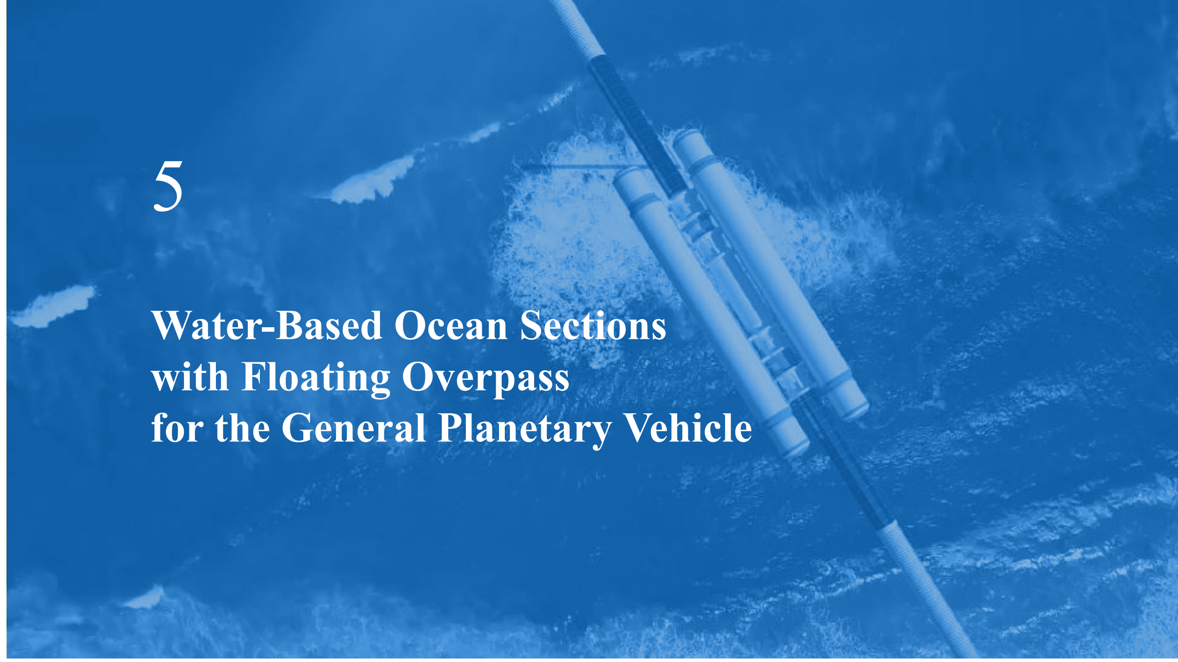

5

Water-Based Ocean Sections with Floating Overpass for the General Planetary Vehicle

5.1 Introduction

Planet Earth and humankind – two objects that are together, but differ from each other. Earth's resources are limited, but humankind's wishes and potential are not restricted. Consequently, limited system cannot include constantly growing subsystem. Thus, there is a moment when the resources need to be attracted beyond the initial system. Depending on the moment of humankind actions, the Earth as liveable planet might survive or not.

To keep liveable earth environment, it is important to remove all harmful elements. One of the ways to accomplish it is space industrialization. K. Tsiolkovsky [1] identified as one of the steps of his programme of space exploration "development of the industrial broadcast". It was the first ever statement about space industrialization. In his programme, K. Tsiolkovsky wrote about manufacturing facilities in space with an unlimited area – there are no gravity forces, with the support from the resources obtained from the Moon and the asteroids – as it provides financial benefits. Furthermore, cargo transfer would also occur in space with the absence of resistant forces and application of other theories, which were seen as fantasy by people, but have become real nowadays.

K. Tsiolkovsky suggested to use rockets with jet engines as vehicles for space exploration. He identified their low productivity and high operating costs, as rockets should transfer high loads of the fuel from the Earth to the outer space in addition to the payloads. Alternative transportation solution was proposed by A. Unitsky in [2]. Industrial Space Necklace "Orbit" (ISN "Orbit") was proposed as an industrialization foundation in this work. Industrial sectors and settlements are presented as separated clusters – EcoCosmoHouses (ECH) [3]. Network of the combined ECHs can reach lengths of several kilometres and be connected in "necklaces" with unlimited length in theory. Each necklace has a circular shape and is in the equatorial plane of the Earth surrounding the planet. The circular General Planetary Vehicle (GPV) is used to lift people and cargo to the space, also surrounding the Earth [3]. Placement of the GPV in the equatorial plane allows to coincide centre of mass of the GPV with the centre of mass of the Earth and keep its position constant. This solution significantly reduces energy consumption of the outer space transportation and limits fl c-tuations of the GPV with respect to the equatorial plane.

Nowadays, equator is also known as the best take-off trajectory for any space flights thus it is the best place to build a support overpass for the GPV. Equatorial placement provides huge benefit due to the use of the natural Earth rotational motion – additional starting speed decreases required used energy for acceleration of the vehicles and energy supplied to the GPV to reach the orbit. Furthermore, equatorial placement eliminates the need of adjusting GPV's trajectory to match it with ISN "Orbit".

According to the scientists of the research centre Stellar World [2], 31,170 km of the equator goes over oceans, seas and rivers. Thus, the GPV overpass construction requires a unique structure to be developed – a floating overpass. Construction of the overpass raises several challenges to ensure stability and safety against the environmental factors, such as water currents, wind, waves, rainfalls and others. Floating overpass should not only act as supports for the GPV, but also it should ensure equal distribution of passengers and cargo along the entire hull of the GPV. Hyperspeed transport can become the key solution to arrange transportation process along the equator. Such system is based on the near-vacuum tunnels with vehicles moving with a speed near the speed of sound in the gaseous medium.

This research discusses in details problems and solutions for construction of the key elements of the sea-shore section of the equatorial transport complex. Section 5.2 presents external environmental factors, having direct impact on the overpass structure. Section 5.3 covers possible options of the floating overpass and concludes with their comparison. Basic principles and specialities are shown in section 5.4. The final one shows the key principles and construction elements of the underwater floating overpass, key conclusions are drawn followed by the directions of the future work.

5.2 Analysis of Environmental Factors Having Impact on the Construction in Equatorial Waters

Development of the engineering solutions requires consideration of the following factors.

Geometry of the ocean floor. Equatorial regions are characterised by the change in the depth, according to [4] with the peak values of 7,680 m in the region of the Romanche Trench (Atlantic ocean), and the average depth fluctuating between 3,000 and 4,190 m [5]. Equator crosses the middle-ocean ridge in three points. This ridge is characterised by the high speed of motion of the tectonic plates – 5–16 cm/year, and frequent earthquakes – up to five times daily in each poi t.

Ocean floor along the equator is a complex and not well explored area, which is completely different form the ground surface with a long construction history. It is required to thoroughly explore the ocean fl or, especially in areas of the anchor support of the overpass. Accurate mapping of the ocean floor is important for the anchors, followed by further geo-ocean research before the beginning of planning and construction works.

Tsunami. According to the analysis in [2], it is possible to conclude that tsunamis along the equator, which have been detected by the stations, are mostly caused by the earthquakes. Strength of tsunamis is distributed from moderate with a height of 1–2 m to very strong with a height of 4–8 m and peaks of 20 m. The strongest tsunami up to date happened in 1883 near the southern seashore of the Sumatra island (Indonesia).

Air temperature regimes. Annual temperature fluctuations (Table 1) were analysed using data for the cities located on the equator, but placed on the opposite sides of the globe – Pontianak (Indonesia) and Macapá (Brazil).

Table 1 – Average monthly temperature (°C) in Pontianak (Indonesia) and Macapá (Brazil) [6, 7]

City/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pontianak	26.9	27.9	27.7	27.8	28.1	28	27.5	27.6	27.9	27.7	27.3	27.2
Macapá	26.1	26.3	26.4	26.7	26.8	26.8	27.2	27.6	27.9	27.8	27.4	26.9

Despite a large distance between cities – 17,826 km, monthly temperature diffe -ence is about 0–1.6 °C with the annual fluctuation less than 1. °C.

Water temperature regimes. According to the scatter plot of temperature change with the depth [8], floats and overpass supports placed above 50 m depth mark will experience warm upper layer of the water. This layer has a temperature fluctuation within a degree and the range of temperatures of 29–30 °C. The temperature is dropping faster with the growth of the depth further (Figure 1).

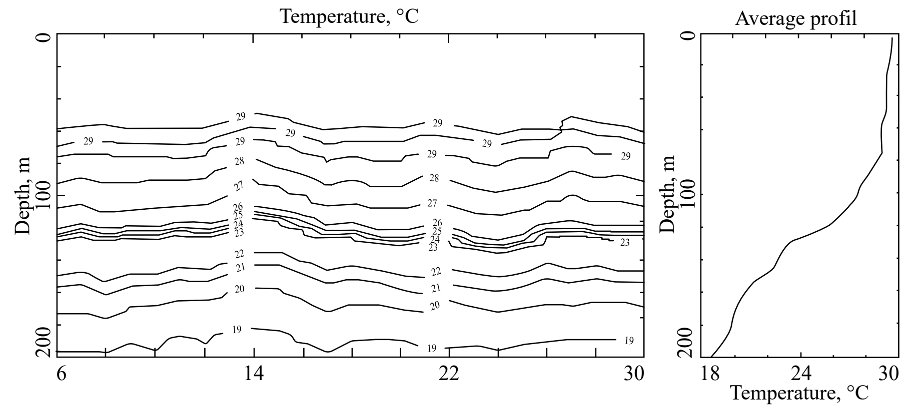

Figure 1 – Change of water temperature in equatorial zone up to the 200 m depth [8]

Salinity of water. Average salinity of the World Ocean is 35 ‰ [9], at the 50 m depth it goes down to 34.4 ‰ [8], with the further increase in depth, salinity is slowly growing (Figure 2). With the given states, the floating overpass should include rust protection of the concrete and steel surfaces.

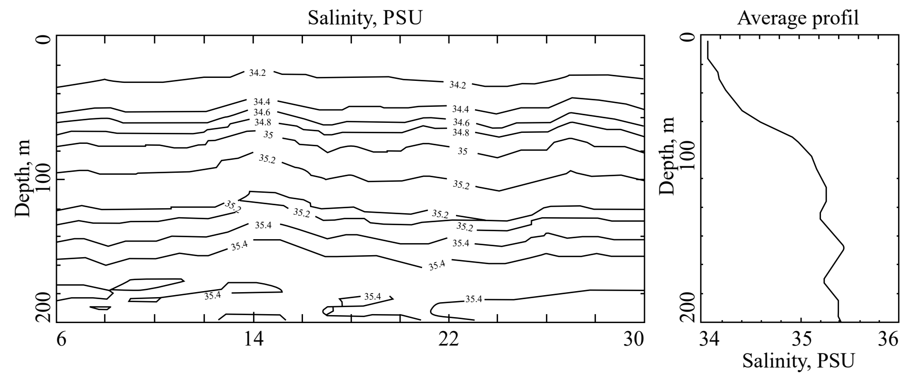

Figure 2 – Change of water salinity in equatorial zone up to 200 m depth [8]

Currents and waves. Equatorial countercurrents exist in the Atlantic and Pacific oceans along the construction line of the overpass (1° yield to the north and the south from the equator) with an average flow speed of 1 m/s directed towards the east. The Northern Passat current is presented in the Indian ocean with an average speed of 2.8 m/s directed to the west. Both currents are at ta depth less than 100 m. As a result, all currents are directed along the overpass and it withstands only axial loading, which elongates the structure and stabilizes it [9, 10]. Equatorial waves have an average height below 1.5 m with a period of 3–6 s. Maximum height reaches 7.5 m [9, 10].

Rainfalls. Equatorial ocean zones are characterised by the heaviest rainfalls on the planet. Equatorial rainfalls are distributed irregularly. According to the research of scientists in the Space Science and Engineering Center University of Wisconsin-Madison [11], the highest amount of rains is seen near Sumatra island located at 3° S, 96° E. Over three years of observation (1979–1981), an average fall of 4,000 mm/year was recorded.

Thunderstorms. According to the analysis in [2], the highest amount of storms is 4–5 % in the area surrounding Sumatra island, and with the lowest amount of 0.1 % in the Pacific ocean area

Wind. Based on the information from the National Climatic Data Center (NCDC) [12], winds in the equatorial zones of the Pacifi , Indian, and Atlantic oceans are, primarily, directed symmetrically to the west with the 30–45° to the axis of the overpass. In the equatorial region, winds from the southern and northern parts of the globe meet each other to create a stable flow with the west direction. Dominating winds have an average speed of 5.9–8.1 m/s with the peaks of 15 m/s.

Pressure. With the depth growth, the pressure is growing by 0.1 atm for every metre of extra depth. There can be seen the pressure of 770 points higher than atmospheric in the Atlantic ocean at the maximum depth of 7,680 m.

Biofouling. Any surface in the water experiences the fouling by the sea organisms. There are more than 4,000 known marine species, including bacteria, algae, and shellfis es [13]. This unwanted colonisation has very serious consequences for the flo ting overpass structure by signifi antly increasing its weight (mass of organisms can reach 100 kg/m2 with the width of 70 mm) and drastically changing the surface roughness, which further increases the loading from the water currents and waves.

Biofouling is influenced by a set of factors, including salinity, pH, temperature, concentration of nutrients, water currents, and solar light intensity. The most common solution to avoid biofouling is to make surfaces, which are not suitable for the biological species and which include poisonous chemicals. Biofouling prevention requires continuous set concentration of the biocides on the painted surface. Toxic chemical should be released from the paint over the long period, which are limited nowadays to 1–5 years [14].

Copper alloys demonstrate the highest corrosion and biofouling resistance among the alternatives [15], even in comparison with stainless steel and glass [16, 17]. They prevent or slow down the biofouling by shellfish s, mussels, and tubular warms. Nevertheless, bacteria, mushrooms, microalgae and their cell-based exudates form a layer of mucus on the copper-based surfaces. Over the time, such surfaces are also affected by the lime plaque, which further leads to a reduction in the protection effect, and, as a result, to the need for mechanical cleaning of the surfaces.

5.3 Overpass Construction Options

The key options include location of the overpass on the water surface, above the water and below the surface of the water at a small depth.

A. Overpass on the Water Surface

Such structure can be seen as an overpass placed on the ocean surface or being raised above the surface at a low height and supported by floats – pontoons. In case of placing the overpass on the water surface, it will separate the Earth by the obstacle into Southern and Northern hemispheres. Considering the high transportation loading of the equator nowadays (Figure 3), it will be impossible to leave certain regions of the world without the sea routes. To create intersections, it is required to develop specifi engineering solutions once the flo ting on-surface overpass is implemented. The following solutions can be used to organise the intersections: lowered or raised sections of the overpass, floating overloading ports, ferry floodgates and others. However, all these solutions change the current straight freight sea pathways and create the "bottle neck" with limited transition capacity.

Another important engineering factor for the overpass on the water surface is its visibility under various weather conditions to prevent collisions with ships. The overpass visibility is affected by the rainfalls, fog, smoke, steam, and other natural activities, which limit the air vision properties. It is required to develop warning system for the ships to inform them about approaching the dangerous zone near the structure.

Design of the overpass should encounter tsunami near the seashores with the heights of 20 m.

There is no need to introduce solutions to compensate temperature deformations due to the low values of temperature changes throughout the year. Daily temperature fluctuations will be compensated by thermal insulation of the overpass

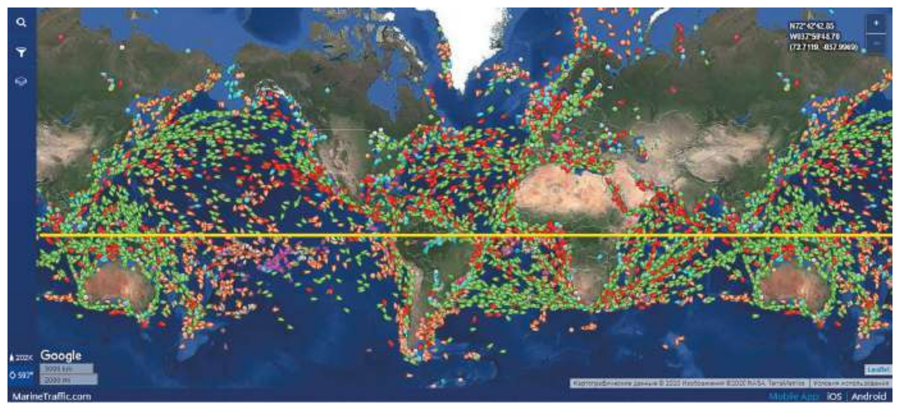

Figure 3 – Ships traffic map on June 25, 2020 [1

B. Overpass Above the Water Level

This type of structure is presented by the overpass raised above the ocean level and supported by floating pontoons. The height and spacing of the supports should be sufficien to have safe ships movement under it. Structure dimensions are limited by the dimensions of the current ocean vehicles. The largest vehicle is ship Pioneering Spirit [19] with the length of 382 m and width of 124 m. The tallest ship is the cruise ship "Symphony of the Seas" with the height of 72 m [20].

Considering top speed of the Pioneering Spirit – 26 km/h (7.2 m/s), its length of 382 m and width of the overpass of 10 m, it will take about 55 s to pass the structure. During this time, the side deflection of the ship can be calculated using (1)

$$S = V_c \times t, \tag{1}$$

where t – motion time under the overpass, s;

V_c – current speed in oceans (current speed fluctuated throughout the day, months and annually, with the maximum values in the summertime), m/s.

The top speed of water currents in the Atlantic, Indian, and Pacific oceans are [21]:

- in Atlantic, Gulfstream current – up to 7.5 m/s;
- in Indian, South Passat current – up to 2.14 m/s;
- in Pacific, Kuroshio current – up to 6.42 m/s

Individual current speed profiles of each region should be considered during the design stage. At this point, the maximum current flow of 7.5 m/s has been accepted for provisional analysis of boundary conditions. Then:

$$S = V_c \times t = 7.5 \times 55 = 412.5 \text{ m}.$$

Considering the width of the ship, the required distance between the supports should be at least 536.5 m to ensure safe passage for the maximum current speed. This value is higher, than the allowed distance of the section of the overpass. It leads to the further limitation – large ships can pass under the fl ating overpass in the specific areas and during reduced current speeds with the direction corrections to balance the current deflection.

The smallest possible distance between supports is B = 150 m, considering 10 % of the safety gap: it includes 124 m of the ship width and safety gaps.

Given the 12 points wind (speed of 30 m/s), the waves height reaches 16.8 m as the maximum value [22].

The smallest possible height is 88.8 m for the 72-metres ship. Considering 10 % safety gap, the height of the overpass should be about 100 m (Figure 4).

Force of gravity is one of the dominant negative factors, which limits the length of the overpass spans and defines the material consumption of the structure. Hundred metres supports, raised above the water surface and supported the entire overpass, have a high weight by themselves, according to [2] – 28,000 tons, excluding the weight of the spans. It signifi antly limits the structure and approaching dimensions. The solution is to separate zones for large ships passage and make them as a single area.

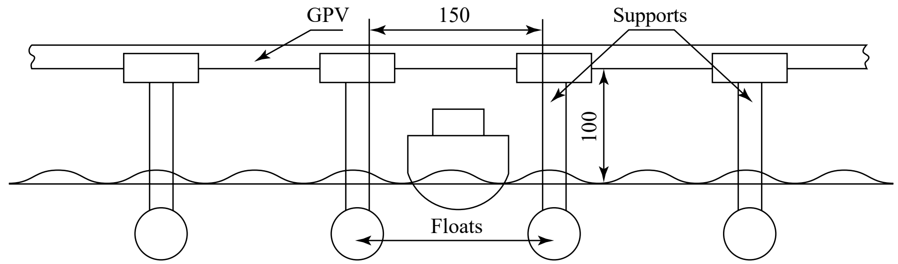

Figure 4 – Dimensions of the ships' passing zone (option)

As a result, supports should be made of steel, aluminium alloys or construction composites with the weight being decreased by two orders of magnitude in comparison with the current solutions.

Heavy rainfalls in the equatorial region have significant impact on the design of the overpass. They increase the needs of the water impermeability and requirements to use elements, which collect and limit impact of the rainwater.

Overpasses have very high safety and reliability requirements (more, than 99.5 %). It also includes lightning protection, which should remove any direct lightning stroke and any electrostatic or magnetic induction. Modern standards also include protection from the induced high electric potentials caused by the lightings.

C. Overpass Below the Water Surface

Floating overpass placed below the water surface is a floating tunnel. It is an innovative concept, which was proposed in several projects, but which was not implemented yet [23]. It should be designed to overcome external impacts, operational and accidental loads with the given strength and rigidity.

The depth of the tunnel is physically limited by the dimensions of the ships and their draft depth. For the largest ship – the Pioneering Spirit – the draft depth is 27 m. Considering the tsunamis and 10 % of the safety gap, the required depth of the floating tunnel is 50 m (Figure 5)

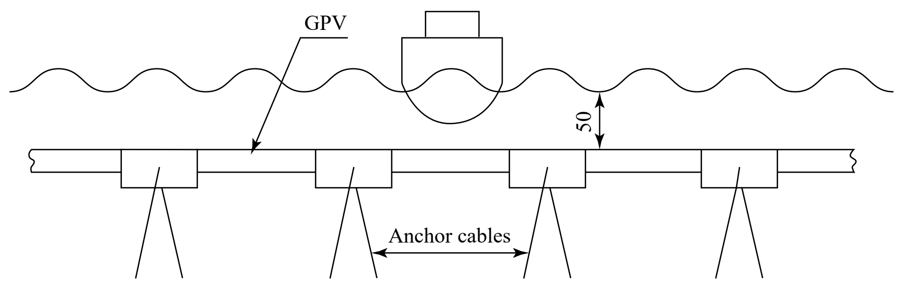

Figure 5 – Dimensions of the ships' passage (option)

Balancing tanks are added to the structure to adjust floating characteristic of the overpass, which can change over time. These tanks allow to adjust behaviour of the tunnel and support the required floating level. Static position of the overpass is provided using anchor cables, which are always under tension due to the high floa - ing rate of the structure. Zero floating should be achieved in the cables to increase their linear rigidity and to remove any sags in the water.

D. Comparison of Support Overpass Designs

All construction factors are combined in Table 2 to compare design parameters.

By analysing list of factors, having impact on the above water and under water overpasses, it is possible to conclude that under water placement has less material consumption needs, has higher technical support and, as a result, it is more fina - cially viable. This solution excludes material-intensive supports of the above-water designs which are impacted by gravitational forces, dynamic loads from winds and waves, excludes thermal deformations and protects the structure from the negative impact of the rainfall and lightning. Based on the analysis above, it is rational to continue further investigation for the underwater floating overpass onl .

Table 2 – Combined table of impacting factors on the floating overpasses
((–) – no impact of the factor; (+) – factor has some impact; (++) – factor has high impact)

Factor	Impact of factor on the design		
	On the surface	Above the surface	Under the water (50 m)
Ocean floor geometr	–	–	–
Tsunami	+	+	–
Air temperature	+	+	–
Water temperature	+	+	+
Water salinity	+	+	+
Current	+	+	+
Waves	+	+	–
Rainfalls	+	+	–
Thunderstorms	+	+	–
Wind	+	+	–
Pressure	+	+	+
Biofouling	+	+	+
Gravity force	+	++	–
Visibility	+	+	–
Total	13	14	5

5.4 Key Elements and Structural Engineering Features of the Floating Underwater Overpass

Ocean section of the floating underwater overpass consists of the following components [3]:

- anchor elements – anchors, pontoons, support nodes;
- forvacuum transport tunnels in two directions;
- embarkation/disembarkation zones for the passengers and service staff;
- production and communal tunnels;
- residential block-stations;
- vehicles;
- support elements of the General Planetary Vehicle for its underwater placement.

A. Overpass Structural Design

Overpass structural design should provide the maximum possible length of spans, be rigid, strong, and include all necessary elements of the system. Considering the length of the overpass – the structure should be universal and fina - cially viable.

The overpass should have a circular (tube) section to achieve equivalent distribution of the loads from the water pressure and to reduce the surface susceptible to biofouling and rusting. Such design allows to remove turbulent of the longitudinal water flows caused by the current and pressure fluctuation on the edges between horizontal and vertical surfaces, like in the boxed shape of the structure presented in [2]. Intensity of biofouling is reduced by the absence of the horizontal surfaces, which makes it difficult for the algae and shellfishes to be attached to the surfa

Floating overpass is a structure, which is continuously placed on the water. Balance between the floating and its weight is important, as this balance control static behaviour of tunnel-float. Considering frequent take-offs of the GPV, it is necessary to compensate weight of the transportation system with the payload with balancing loads. The best option for such balancing system is the use of the sea water pumped into special cavities. These cavities are getting purged once the GPV is landing to keep the required floating level. One of the alternatives is creation of the GPV with neutral flo ting, thus its take-off or landing will have no impact on the flo ting characteristics of the overpass.

According to [24], weight of the one option of the GPV per each metre is: 1,150 kg, additionally 250 kg – weight of the load and 25 kg – weight of the passengers. To achieve neutral buoyancy of the tunnel, it is needed to calculate balance between weight of the cross section equal to the weight of the displaced water.

Figure 6 shows recommended packaging solution of the transit station. It is separated geometrically intro four functional zones – two zones for hyperspeed transport motion in forvacuum tunnel in diff rent directions, and two zones dedicated for embarkation/disembarkation of the passengers. Two ballast tanks are placed along the horizontal axis of the cross section and have a diameter of 1 m. The weight of each metre of the balancing system is 1,600 kg once they are filled with the sea water, which is equal to the weight of each metre of the loaded GPV with 10 % safety gap, once the GPV is placed on the water. If the GPV has neutral buoyance and underwater starting point, then the size of the balancing tanks can be reduced.

Packaging solution presented in Figure 6 has an outer diameter of 9 m. Weight of the structure should be 64,850 kg per each metre to balance the weight of the displaced water, considering the average sea water density in equatorial zone of 1,020 kg/m3. Given the density of the concrete as the main construction material of 2,500 kg/m3, the reduced cross-sectional area will be 26 m2

As the tunnel is placed at a depth of about 50 m, it should be fully waterproofed, be resistant to the salty sea water and should be protected from the impacts of hydrostatic and hydrodynamic forces. For example, it should withstand collisions with a whale or with a submarine.

Overpass shell is made of four layers. The outer layer is made of stainless alloys to resist to the salty oceanic water and biofouling. Second and third layers are made of foam materials to provide zone of elastic deformation of the tunnel from the environmental loads. Fourth layer is made of steel reinforced concrete, which provides the required strength and weight. In addition, final layer is the key construction element of the internal components. The tunnel structure is shown in Figure 7.

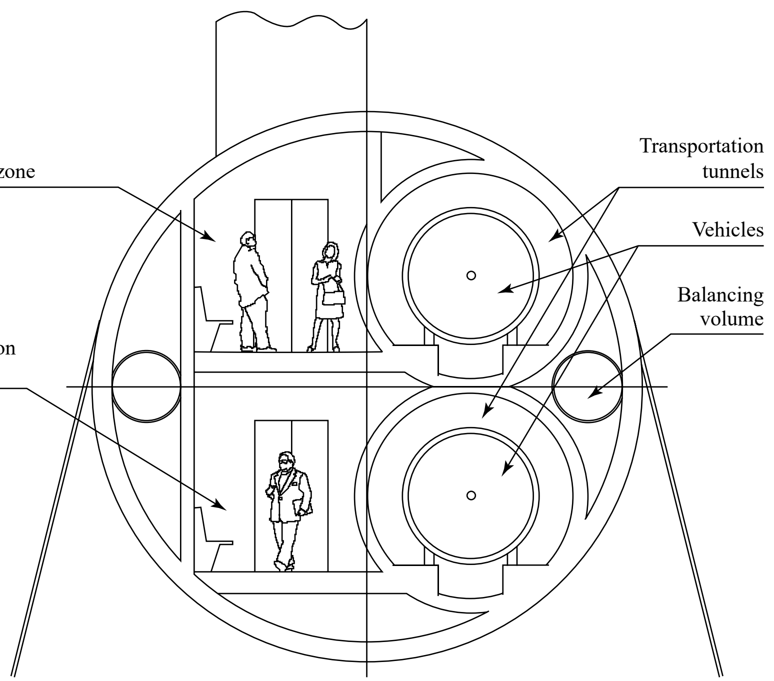

Figure 6 – Floating overpass packaging solution in the station area

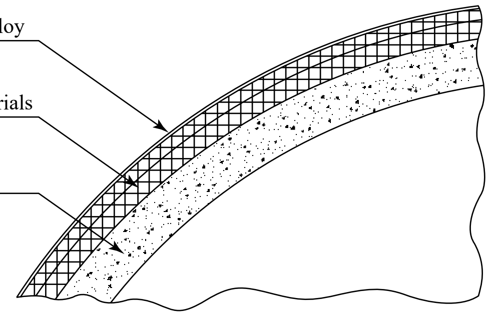

Figure 7 – Tunnel's shell structure (option)

Introduction of the longitudinal water transmission pipe with a diameter of 1.5 m (it is not shown in the Figure) will allow to reduce the amount of the used concrete by 1,800 kg and it will ensure proper fresh water supply of the GPV (including delivery to the orbit and excessive amount – along the equator). As the overpass construction line goes through the Amazon river, which annually discharges about 6,300 кm3 of the fresh water into the Atlantic ocean [20], there is no need in construction of additional facilities and plants for desalination of the salt water. As was proposed in [25], it is possible to take fresh water from the Amazon river basin after it has reached the ocean. An important factor is in the possibility of obtaining fresh water from the ocean's surface located 1–2 km away from the seashore of Brazil. Such placement of the collection points allows to reduce ecological resistance and degradation of the Amazon river basin from the overpass construction. In addition, it will not create any obstacles for the water transportation routes. Hydrogeographic research demonstrated that fresh water mark of the Amazon river above the continental oceanic shelf has the height of 3–10 m and the width of 80 km [26].

Trajectory of the underwater overpass should be marked on all maps and it should be added to the electronic navigation databases. There is a need to place light-based and sound – based signals on the surface of the ocean along the floating overpass.

B. Ocean Floor Anchor-Based Fixation System

Ocean floor has complex geometry, and it makes impossible to use universal solutions. In the proposed system, there are two types of fixation in use: negatively buoyance anchors and positively buoyance fl ats. These two types of fi tures will be applied to various sections of the overpass and it will allow to balance positive and negative buoyance. Once the floating overpass has positive buoyance, it will be fixed at a certain place with the tensed cables connected to the ocean floo . Sections of the overpass with negative buoyance will be suspended with pontoones, floats or, in some cases, with the supports placed on the ocean floo .

There are following types of the anchor nodes:

- cable anchoring at the bottom. This type is based on the reversed pendulum principle. A special float is integrated in the tunnel at the connection point to push the structure upwards but being suspended by the cables. When this method is in use, there is a need to provide continuous tension forces to the cables. Tensed cables can be placed vertically, which is suitable for the areas with the longitudinally directed water current. Combined placement of the cables – vertical and/or angled – can be used for the sections with transverse water current direction;

- support of the tunnel with pontoons. This solution uses the tunnel as a load to increase the weight and keep in place the floating element. This system does not depend on the depth, but it is sensitive to wind, waves, currents and possible collisions with ships. Additional devices should be integrated in the system to limit displacements from the environmental loads;
- supported overpass (with columns) is an underwater bridge. Supports can be either tensed or compressed. Depth plays a key role in this system, as its permissible limit is up to 100 m.

The overpass structure should ensure that in case of loss of one of the anchor elements, the entire system will remain operable. It can be achieved by duplications and redundancies.

Key types of the anchors are shown in Figure 8.

As the tunnel passes through the Atlantic, Indian, and Pacific oceans, it will be loaded with the currents with high speed. The tunnel should not deflect under the water jet impact and keep its shape and trajectory. Thus, it is proposed to restrain the tunnel on the ocean floor with steel cables and anchors [3]. Spacing and strength of the anchor elements should be evaluated individually for each region using their specifi s and cumulative forces, acting on the overpass, including external and internal one.

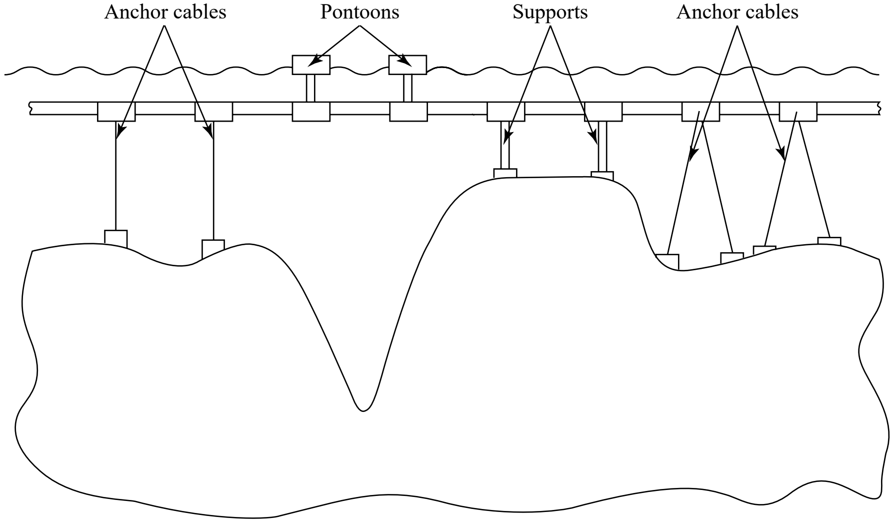

Figure 8 – Key types of anchors for the floating tunne

The floating overpass will be placed below the surface of the waves and outside the wind pressure zone. Thus, fixed oceanic water currents will create the main load. Anchors should resist to these currents. However, they are not the largest forces, which should be suspended by the anchors – vertical in-depth waves from the water masses mix and rare tsunamis are more dangerous for the structure. Deep trim of passing ships should not have any dynamic impact on the structure. Nevertheless, the overpass should not be located too deep, otherwise its maintenance will be difficul and expensive. Authors suggest the depth of 45–60 m. It is possible to use scuba diving at the given depths, as according to [27], the lowest limit for technical diving is 60 m. Research [28] also demonstrated, that at 100 m depth mark the metal cables and tubes will be influenced by the geomagnetic disturbances, which should be considered in the overpass design.

Deep sea anchors are widely used in oil platforms. They are built as a concrete block with high mass securely fastened by tensed steel cables. The balance between floating and hydrodynamic resistance defines the free fall or constant velocity of the torpedo-shaped anchors in the water. Field tests were conducted in [29] to prove possibility of underwater placement of the nuclear wastes encapsulated in a free fall box weighing 2,000 kg. The box is dynamically stabilized and moves with a constant speed close to 45 m/s before it hits the ocean floo , when under its own impulse, it penetrates and buried itself. It was proven that a streamlined torpedo made of steel can easily reach 40 m depth under the hard surface of the ocean floor [30]

Anchor is acting as a pile, which is kept in place by the friction forces. The number of anchors depends for each connection node and it should be calculated to minimise deflection of the floating overpass under external loading conditions. One of the key advantages of using deep sea anchors is their theoretically unlimited number and possibility to "drop an anchor" by disconnecting cables without any further negative impacts in case of the earthquakes or critical dislocation of the crustal plates.

C. Power Supply of Floating Overpass

Power supply of the floating overpass can be divided into two zones

- first one is internal systems – operation of transportation systems, lightning and control system, communication, ventilation and conditioning systems, pumping system and others;
- second zone includes all external power consumers – signal beacons and warning buoys, radars, security and communication systems.

There are various power sources for the overpass, however modern tendencies and ecological friendliness of the project require to use renewable energy sources. The obvious sources are wind and solar energies, as equatorial region can be characterised by stable solar irradiance and fixed winds directions. Nevertheless, the most efficient energy source is the wave energy from the natural oceanic currents.

They do not depend on the daytime, solar position or the seasons. Hydroturbines of the underwater power stations, utilising water currents, can be installed separately or directly on the floating tunnels of the GPV s overpass.

Water currents in equatorial region are directed mostly (85–90 %) along the overpass and have a speed of 1 m/s in the Pacifi and Atlantic oceans and 2.8 m/s in the Indian ocean. Underwater turbines can receive energy from the processes of hydrodynamic lifting and drag. These turbines have specific rotor blades, generator to convert rotational energy into electricity, and transmission system for the generated energy. It is possible to evaluate energy of a single turbine P_t (W), which can be obtained from a water flo , using equation (2):

$$P_t = \frac{1}{2} C_P S \rho V^3, \tag{2}$$

where C_P – unitless coefficien of turbine efficien , modern turbines reach values of C_P = 0.4–0.5;

S – working area of the blades, m2;

ρ – sea water density, kg/m3;

V – speed of the current, m/s.

Initial evaluation provides for each square metre of the operating area of the turbine approximately P_{t1} = 230 W, in the Atlantic and Pacifi oceans, and P_{t1} = 5,040 W in the Indian ocean.

5.5 Conclusions and Future Work

The floating overpass is a take-off and landing zone for the GPV and an integral element of terrestrial transportation process for ISN "Orbit". It supports logistics along equator, ensures equal distribution of cargo and passengers along the GPV. Floating overpass, being submerged to a depth of 50 m, will experience a smaller number of negative impacts, therefore, it will be safer. Furthermore, it will require less construction materials in comparison with the overpass above the water level, and, consequently, it will have lower cost. This structure will fulfill the needs of ISN "Orbit" in fresh water and it will allow to place underwater generators to power up the entire complex with minimal additional power consumption.

Future work is dedicated towards research regarding tunnel cross-section with its detailed calculation using underwater currents velocities, material and labour consumptions, construction and installation technologies development, as well as resistance to vandalism (not only from the people, but also from the sea animals) and terrorism. Problems of biofouling is another direction of the research to ensure required cleanliness of the underwater overpass.

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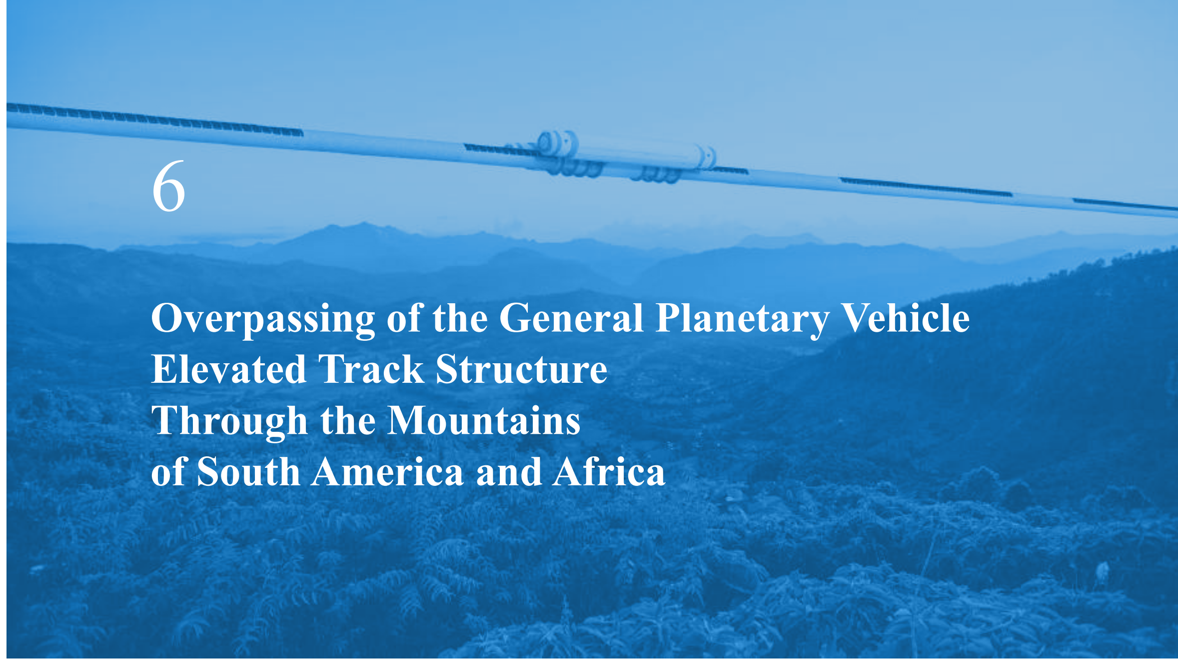

6 Overpassing of the General Planetary Vehicle Elevated Track Structure Through the Mountains of South America and Africa

6.1 Introduction

Roads serve as connecting arteries for all industries. In course of their construction, you always have to either adapt to the relief using elevated roads, bridges, tunnels, or change the relief by cutting and filling extra elevations. Such types of works have been executing for thousands of years. The same methods are required for construction of an equatorial launch elevated track [1]. It serves as the basis for construction, adjustment, maintenance and launch of the General Planetary Vehicle (GPV).

The equator of our planet passes through valleys, mountains and oceans. And each deviation from the horizontal level has to be evaluated separately. Solutions of the topical issues have already been previously considered in [2].

The main obstacles in the construction of the equatorial launch platform considered in this paper are the mountains: the East African Highlands (Mount Kilimanjaro) in Africa and the Andes (Mount Chimborazo) in South America.

Both heights of the supports and depth of the excavations depend on the trajectory of the passing area over the uneven areas in terms of the track structure. The shape also affect the operating conditions of linear flywheels inside the GPV. Each deviation from a straight path adds extra load from the centrifugal acceleration on to linear electromagnetic motor and magnetic cushion holding two linear rotors. These extra loads can be higher by an order of magnitude as compared to the nominal load per each running metre of the GPV. It was included in the development of the overpass design.

Since the exact standard parameters of the GPV operation are not available yet, taking into account vertical irregularities of a large radius (about 1,000 km), since nowadays conceptual structural designs and options are being studied, therefore, this research illustrates several simplified options for elevated track passage with diffe - ent radii of curvature.

6.2 Initial Data for Study

Terrain elevations along the equator from the Google Earth resource [3] were used for longitudinal profile development. In Africa, a 280-kilometre long track section is considered with an elevation of 3,460 m above sea level (Figure 1). In South America, a 150-kilometre long track section is considered with an elevation of 4,691 m above sea level (Figure 2).

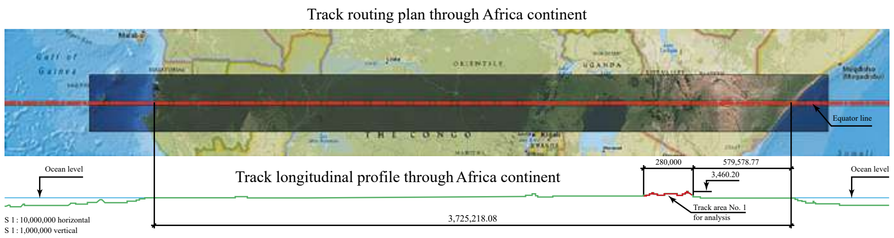

Figure 1 – Scheme of passing of the GPV elevated track structure through Africa continent

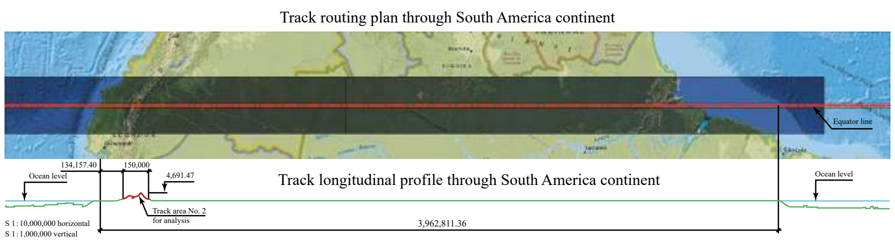

Figure 2 – Scheme of passing of the GPV elevated track structure through South America continent

When designing railways and roads, rules for transition curves arrangement were accepted [4, 5]. However, the criteria used therefor are not suitable to meet design requirements for equatorial launch elevated track. They are selected so that to provide for superior comfort to the passengers. In our case, the construction criteria shall ensure optimal rotor operation during take-off and landing of the GPV on overpass, as well as landing thereon upon orbit flight completion. The term “comfort”, from the engineering point of view only, also applies to GPV operation – its linear electric motors and magnetic cushion, that holds linear rotors moving at cosmic velocities.

6.3 Through-Mountain Trajectory Selection

The first step includes definition of the parameters for the construction of radial and transition curves while designing a through-mountain trajectory of the elevated track structure. Parameters of the GPV are constant in one of the possible designs mentioned below. Rotor linear velocity along a vacuum channel is 12 km/s with the mass of 450 kg/m. Weight of the GPV running metre plus cargo was estimated at 1,150 kg/m.

Three sets of parameters for elevated track construction are illustrated in Table 1.

Table 1 – Longitudinal trajectory parameters of elevated track structure

Minimum curvature radius, km	Acceleration increment in transition track section, m/s^3	Centrifugal acceleration, m/s^2	Lateral acceleration on a rotor, g	Lifting capacity, t/m
100	–	1,440	146.8	66.1
1,000	–	144	14.68	6.6
5,760	10	25	2.55	1.15

First two options of routing were built without transition curves between track section with different curve radii (to facilitate construction). That is why acceleration increment is not determined and, theoretically, goes into infinit . When designing ordinary roads, the absence of transition curves causes clash in traffic. However, the influence of such a solution (lack of transition curves) on rotor movement inside the GPV has not been studied yet. However, such measure could save resources during construction, although the complication of the design of the GPV and increase in its cost will probably not only cross out the estimated savings, but also make the functioning of this giant aircraft unstable and unsafe.

In the third option, the radius is adjusted so that the lifting force after the movement of the rotors equals the weight of the GPV.

6.4 Study of Selected Trajectories

A. Trajectory of Elevated Track Structure

Movement trajectories were designed for all the options presented in Table 1. The outcome is summarised in Table 2.

One can come to the obvious conclusion that the smaller the radius of curvature of the elevated track structure, the better it follows the terrain of the ground and the more minimal will be such parameters as: the volume of earthworks, the maximum depth of excavations and the maximum height of supports. At the same time, the passage of Mount Kilimanjaro with large radii (1,000 km or more) will require a greater earthwork volume than when passing through the higher Andes.

Table 2 – Results of elevated track structure design

Section of GPV	Minimum curvature radius, km	Earthwork volume, mln m^3	Maximum excavation depth, m	Maximum support height, m
East African Highlands (Mount Kilimanjaro), Africa (Figure 3.1)	100	873	40	300
	1,000	15,000	600	567
	5,760	28,300	1,174	700
The Andes (Mount Chimborazo), South America (Figure 3.2)	100	1,200	323	809
	1,000	13,000	1,242	998
	5,760	27,200	1,734	947

Furthermore, it is noteworthy to pay attention to the third designed diagram with a radius of 5,760 km. When determining vertical accelerations on the vertical trajectory of the elevated track structure in Africa, it is obvious that the more accurately we follow the terrain, the more often and sharp, closer to clash, the direction of vertical accelerations changes to the opposite (Figures 4.1, 4.2). Resulting from this is that the transition curves should be studied very carefully since their non-optimal trajectory could destabilize the GPV operation during its take-off and landing

In South America, the trajectory of the elevated track structure deviates more from the terrain, therefore, the acceleration increments occur on the longer track sections without a steady alternation of direction with a jerk (Figures 5.1, 5.2).

Detailed calculation of the GPV rotors movement will support a more clear understanding of the benefits of each method and will allow to select the best one.

B. Support and Excavation Arrangement

Passage of mountain groups using tunnels is not possible – a peculiarity of construction of equatorial launch elevated track structure. A prerequisite is the presence of an open excavation for lifting the GPV. An example of the construction is shown in Figure 6.

Digging excavations can be executed by drilling and blasting, using explosive energy to separate and loosen the rocks. Labour costs and demand for material and technical resources directly depend on the rock strength. The stronger it is, the harder it should be treated (mined) and will require more explosive force. Due to the lack of soil report data from the construction sites for the GPV track structure, the composition of rocks is adopted based on the data from free sources. According to the received information [6], the rock mass along the equatorial route consists of sandstones, siltstones, shales, granites, and quartzites.

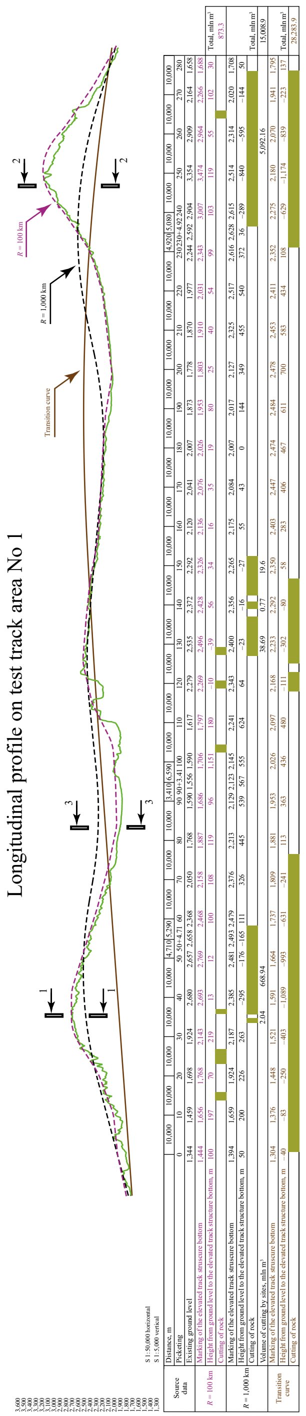

Figure 3.1 – Track route longitudinal profile in the East African Highlands (Mount Kilimanjaro), Africa

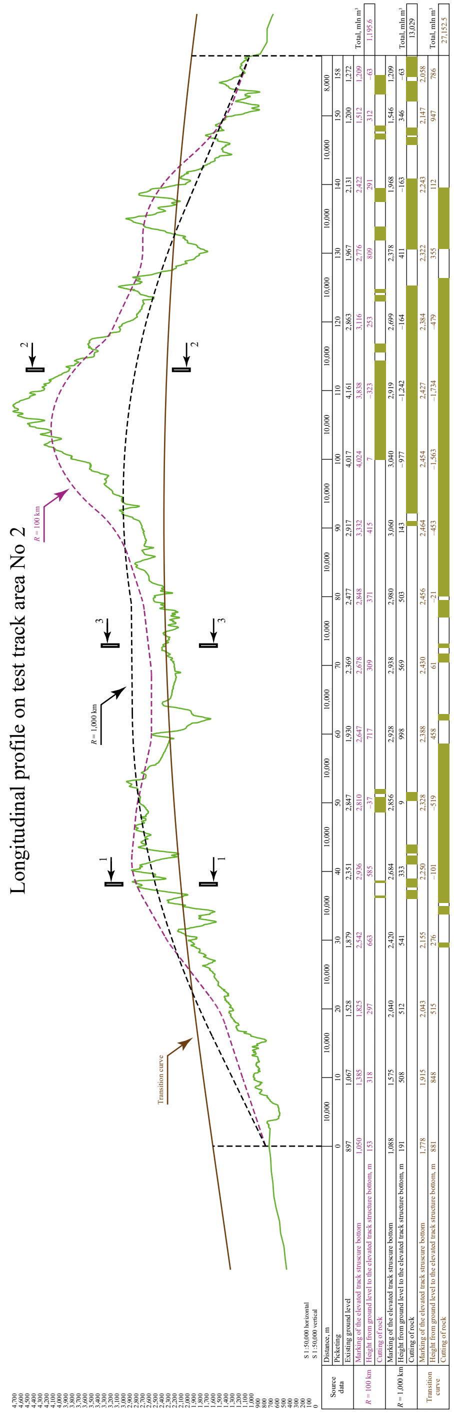

Figure 3.2 – Track route longitudinal profile in the Andes (Mount Chimborazo), South America

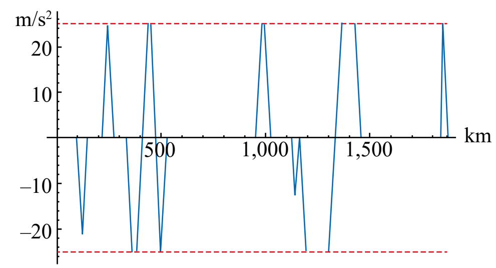

Figure 4.1 – Vertical acceleration on track No. 1, Africa (option)

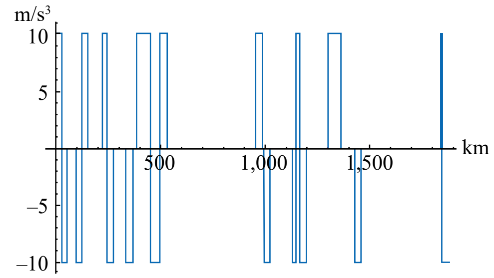

Figure 4.2 – Acceleration increment on track No. 1, Africa

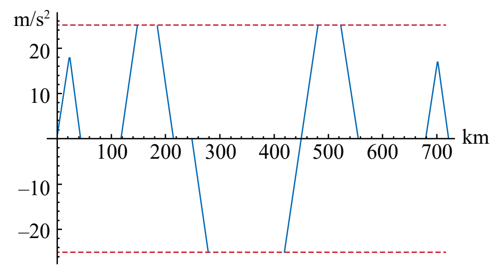

Figure 5.1 – Vertical acceleration on track No. 2, South America (option)

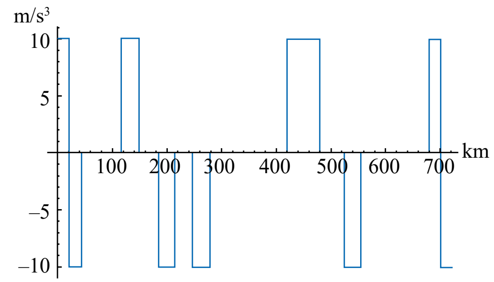

Figure 5.2 – Acceleration increment on track No. 2, South America

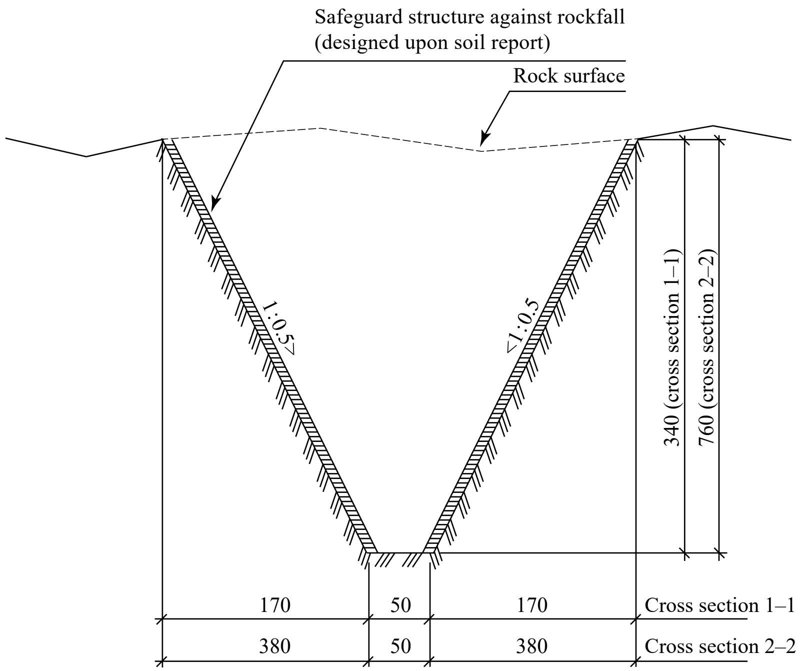

Figure 6 – Excavation scheme (option) (all dimensions are in metres)

Granites and quartzites, as the most labour-consuming rocks with respect to mining, were considered for labour input assessment in the current research. Under conditions from [7] the value of 451,100 man-hours were evaluated as a labour input for mining 1 mln m^3 of rock. Mined rock volume is illustrated in Figures 3.1, 3.2.

Under conditions from [8], general and local stability of excavation were calculated under the initial data comprising the following elements:

- construction site layout plan;
- seismic conditions on the construction site;
- hydrogeological and soil conditions of the construction site illustrating the areas subjected to hazardous geological-engineering processes;
- design values of strength and deformation properties of undisturbed rock with respect to forecast changes of these values due to seasonality and over large time periods;
- location of existing building/structures (including protective ones), roads, and if any – values of man-induced loads from them.

To safeguard excavation slopes (Figure 6) depending on the above-stated initial data, the following steps were identified

- alternation of slope shape (for stability increase against shear force decrease via unloading the upper (active) part of a landslide);

- control of surface water discharge (to ensure slope stability increase due to mitigation of their erosion on slope surface, their accumulation exclusion in lowlands and avoidance of their infiltration into landslide slopes ;
- control of underground water discharge (to provide for slope stability increase due to mitigation of their erosion and softening on soils, avoidance of their infi -tration into landslide slopes, the shear force decreases over sliding surfaces at wetting, hydrostatic and filtration pressure decrease)
- use of protective facilities as flexib e safeguarding structure of slopes against rockfall (Figure 7), or slope-strengthening structures.

It is possible to use anchor-based structures to strengthen the excavation slopes (Figures 8, 9). Anchors are used to fi unstable areas of soil and rock slopes as free-standing safeguarding structures with local anti-shear elements (washers, slabs, beams, chords, etc.), together with continuous metal, reinforced-concrete or mesh covers, as well as combining with retaining walls, gravity, pile and Barrette structures.

The main condition for the use of anchor structures is the presence of good-bearing soils at a sufficien distance from the protected surface, in which the root section of the anchor is located. In construction practice soil anchors (anchor piles) are having dimensions from 10–15 m up to 50–60 m in length.

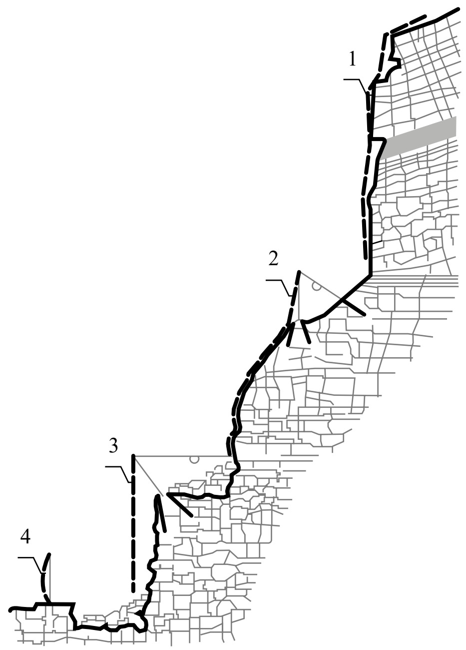

Figure 7 – Example of flexible safeguarding structure against rockfall under [9]
1 – passive cover mesh; 2 – hybrid barrier with a cover mesh;
3 – hybrid barrier with a suspended mesh; 4 – flexible barrie

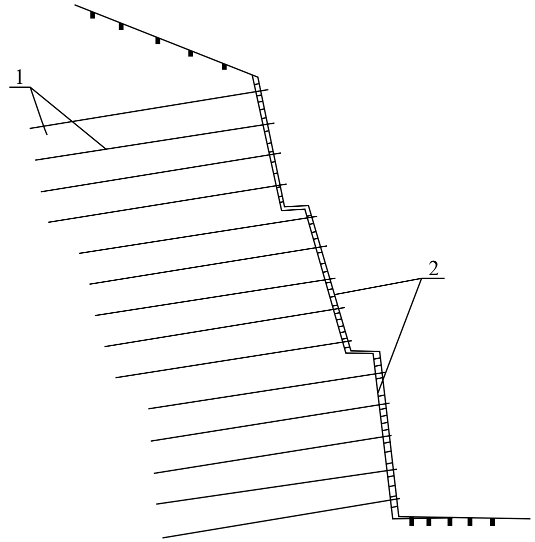

Figure 8 – Example of slope anchorage: 1 – mortar injection anchor; 2 – anti-sher slab

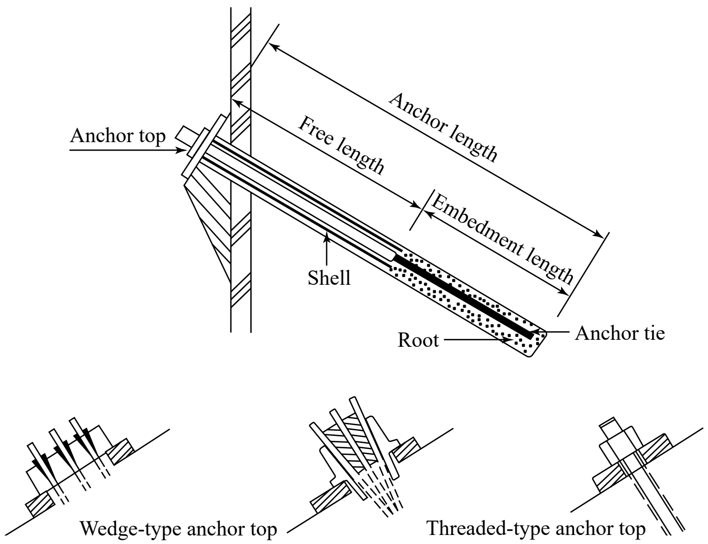

Figure 9 – Example of mortar injection anchors

Supports of the elevated track structure are advisably made of reinforced-concrete of 300 m high (equates to the height of the highest bridge supports). The required height could be reached by local fillings constructed from rock excavated (mined) in course of cutting (Figure 10).

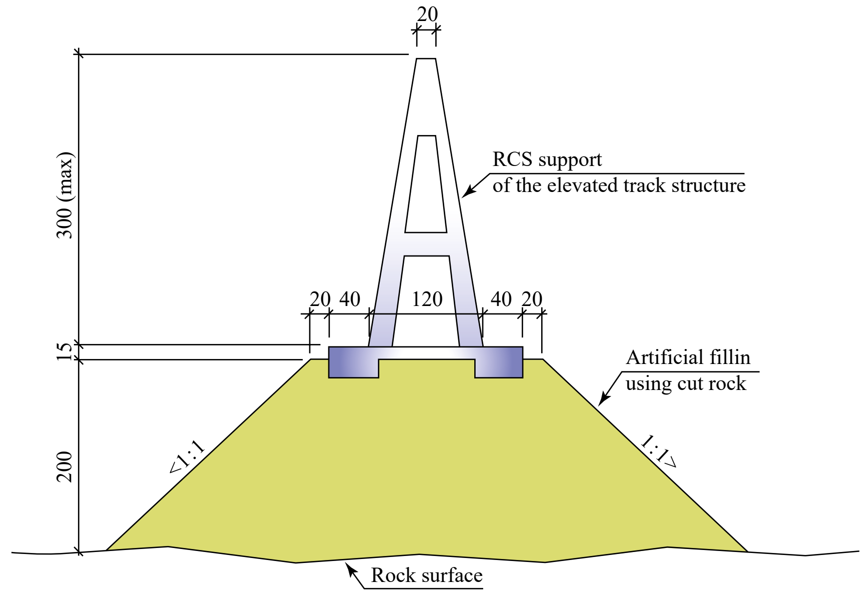

Figure 10 – Example of reinforced-concrete structures (option)

6.5 Conclusions and Future Work

The enlarged radius of trajectory's vertical curves of the elevated track is more resource-demanding, with increased height of intermediate supports and with the deeper and bigger excavation area. Final parameters of linear electric motors, magnetic cushions of the GPV rotors should be fi alized to have accurate evaluation of the required resources and costs, thus, allowing for a considerable decrease of construction expenses for launching elevated track structures, as well as for optimisation of a passage trajectory through the mounains.

Calculation output shows that if the trajectory curve radius of the elevated track structure does not exceed 5,760 km, the lifting force due to centrifugal force exceeds the GPV weight – 1,150 kg/m. If a smaller curve radius is required against flat track sections, stronger fixators to hold the GPVs steady at start sh uld be used.

Design of excavations and supports of an equatorial launch elevated track structure directly depends on the terrain and geological conditions of the area. Thorough study and survey are required for each such structure.

The calculation showed that 1,000–5,000 km range is the best vertical curve radius of the elevated track structure that any GPV must follow at taking off and landing. Thorough design of transition curves between adjacent sections of all the curves is required, because otherwise the GPV to possible resonance phenomena in these areas is not capable to normally take off

Profound analysis is required of a passage of any mountain peak to find the better excavation depth therein and better height of supports (all the support, not just the maximal height of one of them) on the adjacent sections to minimize the total cost of excavation and adjacent supports.

Meanwhile, rock from each excavation should use for construction of local fil - ings for the supports on adjacent sections of the elevated track structure. Surplus of firm rock could be used for concrete manufacture for not only supports of the elevated track structure, but for infrastructure also. First of all, for Equatorial Linear City, for work and accommodation of 100 mln persons that serve the GPVs, TransNet equatorial network, built under Unitsky String Technologies (UST) and space industry created on low equatorial orbits.

Narrowing excavations up to 15 m (minimal width of a safe corridor for the GPV taking off and landing) at the bottom, and cutting their steeper side walls (at vertical deviation by only 1 m per 100 m of height) allow to reduce excavation volume in rocks by many times even if excavatings deeper. Installation of extra anchors could be more cost-effective than vast excavations

We advise making excavations deeper to make a curve radius of a taking off-l nding elevated track structure bigger and reduce the maximum height of supports up to 200–300 m. Over high supports (while there will be rather many of them) could be less cost-effective than extra earthwork. Besides that, it is possible to make the supports better from a structural point of view: they could be less resource-demanding than typical bridge supports illustrated in the analysis.

Anyway, even in the first approximation, having studied the issue of mountains passage in Africa and South America, from an engineering point of view, makes its resolution rather positive. However, later at further research, a comprehensive technical and economic analysis should be performed concerning all the systems of transport-infrastructural communicator, which will be created during the next decades on the GPV technological platform.

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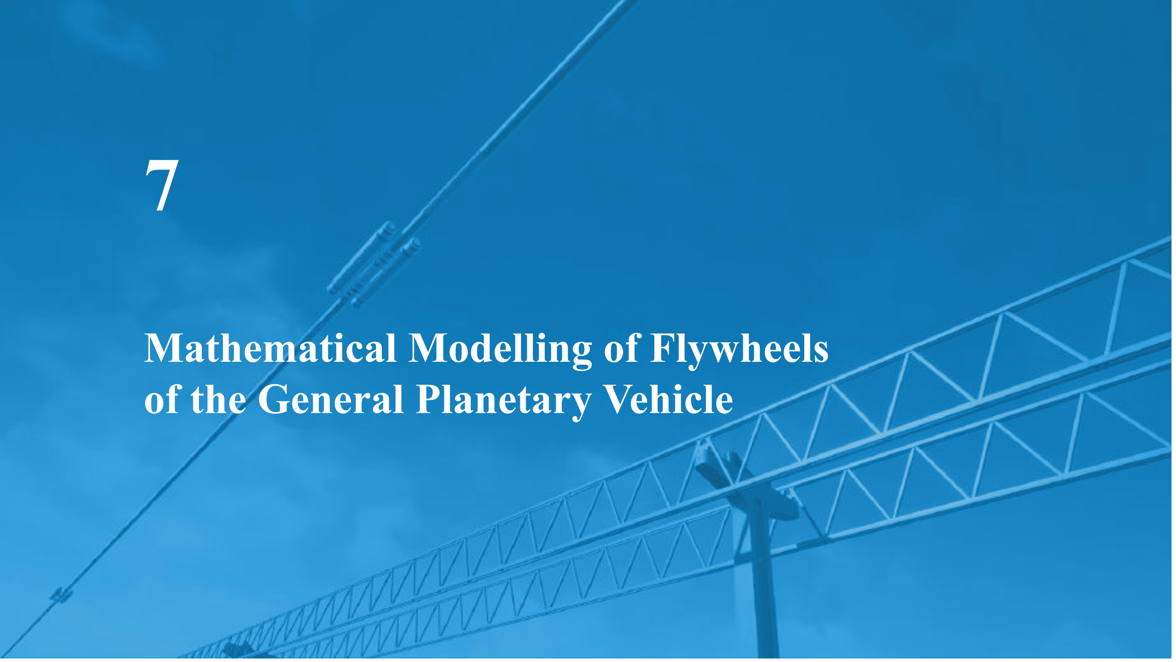


7

Mathematical Modelling of Flywheels of the General Planetary Vehicle

7.1 Chapter Overview

Finite element analysis (FEA) is a modern advanced computational technique for the mathematical of all possible structures and their internal processes. Tasks, which required many hours of work to analyse, now cause no particular difficultie for professionals who are engaged in FEA-driven calculations. The fundamental idea of calculation processes in FEA is discretization of the calculation process by elements or by time. Furthermore, a combined calculation of a discrete model performed over the given time periods can be done, taking into account the inertial components of the system, as it was done in this paper. In general, the FEA gives results that converge with the physical models with an accuracy of up to 5 % for a static calculations and up to 10 % for a dynamic systems. The accuracy of the obtained results directly depends on the detailed design elaboration of the model.

This research presents the model of the General Planetary Vehicle (GPV), a design of which is presented in Figure 1 [1]. The authors modelled the dynamic behaviour of the system during the following processes: acceleration, initial take-off, and the ascent to a given orbit with the required orbital velocity. In addition, paper presented results of a computational modelling, which was performed in the ANSYS software complex (for fin te element model) and Mathcad (diff rential equations of the structure behaviour at different stages of work). In addition, chapter analyses stability of the system and impact of the equatorial elevation changes on the GPV operation. In general, the developed model consists of three tapes inextricably

connected along the vertical axis (in the polar coordinate system) with the following properties: two tapes imitate the flywheels and the third tape – the rotor housing. Each circular tape was discretized (Figure 2).

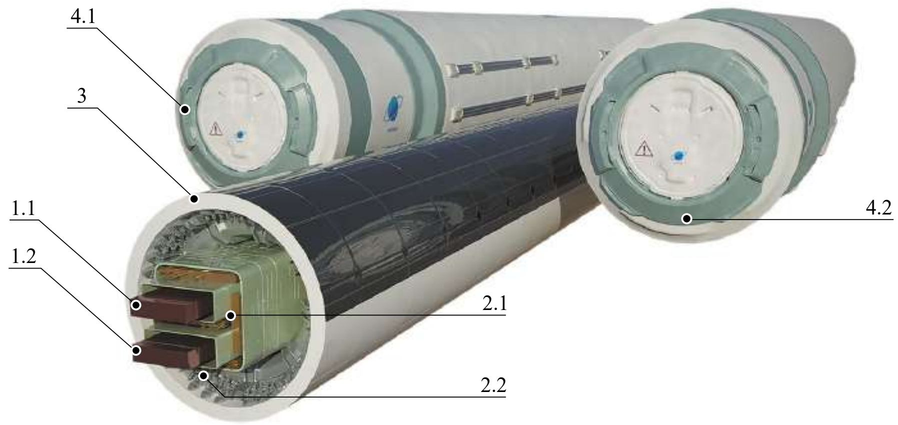


Figure 1 – GPV design: 1.1 and 1.2 – belt flywheels;
2.1 and 2.2 – magnetic suspension systems and linear electric motor;
3 – body; 4.1 and 4.2 – containers with cargo (visualisation) [1]

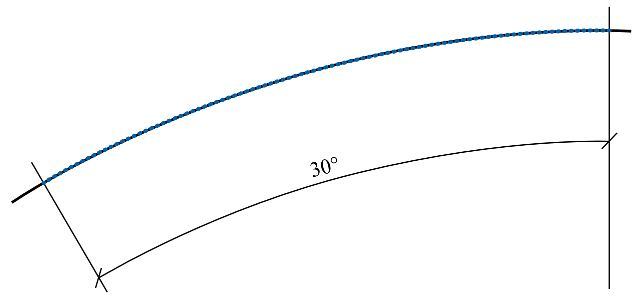


Figure 2 – Number of points on the surface of a sector with a 30° internal angle.
The total discretization of the model is 1,000 points for each tape

7.2 Mathematical Model of the General Planetary Vehicle

Flywheel and shell structures are connected using a No Separation contact pair, which provides zero friction and without the possibility of separation. This system eliminates the mutual influence of the flywheels on each other, but, at the same time, allows them to deform together under the impact of the centrifugal force.

There are several forces acting on the system (Figure 3): F_1, F_2 are the elastic forces that integrate the scheme into a unified structure, G is the Earth gravitational force,

Q is the atmospheric drag force, F is the resultant of the F_1 and F_2 forces, $\dot{\varphi}$ is the angular rotor speed, φ is the angle of rotation of the system under consideration in relation to the axis of coordinates, ω_p is the Earth angular velocity (initial velocity of the housing rotation), δ is the central angle of the arc, $\dot{r}$ is the radial velocity of the rotor and the shell, r is the current radius of the rotor orbit, R is the Earth radius.

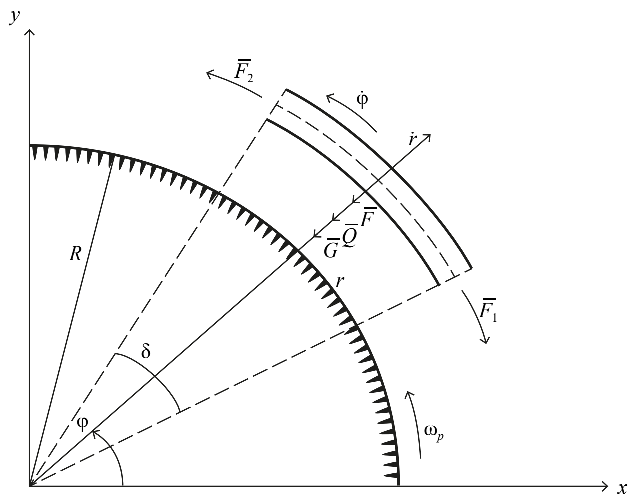


Figure 3 – Diagram of the effect of forces on the GP segment

The main task of the developed study was to optimise masses of the flywheels and the rotor housing to achieve optimal efficienc of the system and get the required stabilization at a given orbit.

Parameters used in the task being calculated include constants and set values, as given below.

Constant parameters:

$G = 6.67408 \times 10^{-11}$ m3s^{-2}kg^{-1} – universal gravitational constant;

$M_{Earth} = 5.9723 \times 10^{24}$ kg – mass of the Earth;

$V_{1.e} = 465.1$ m/s – line speed of the Earth's rotation at the equator;

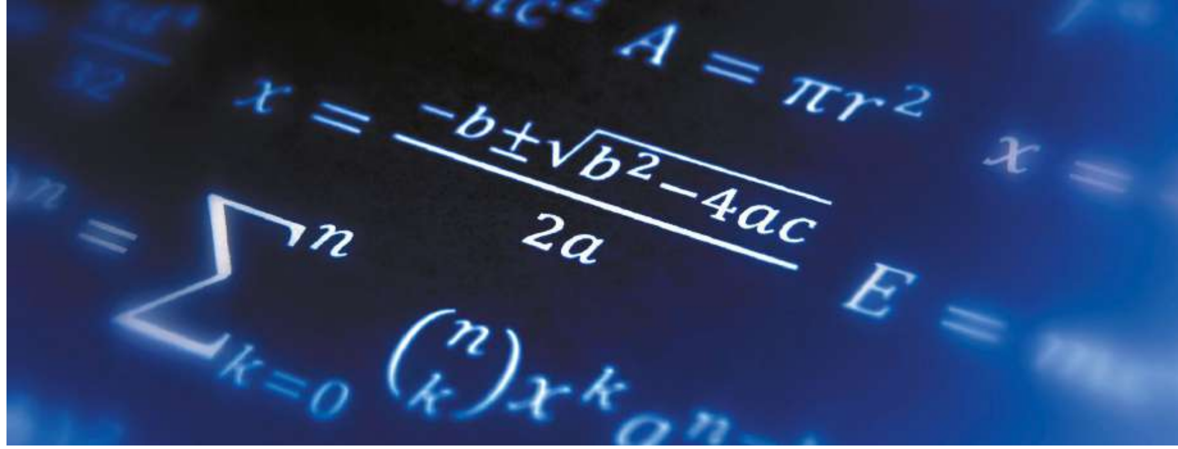
$R_e = 6{,}378.137$ km – Earth's equatorial radius;

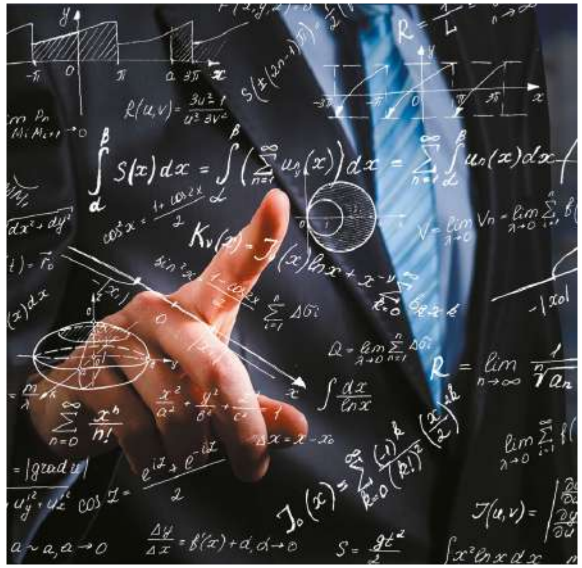
$R_p = 6{,}356.752$ km – Earth's polar radius;

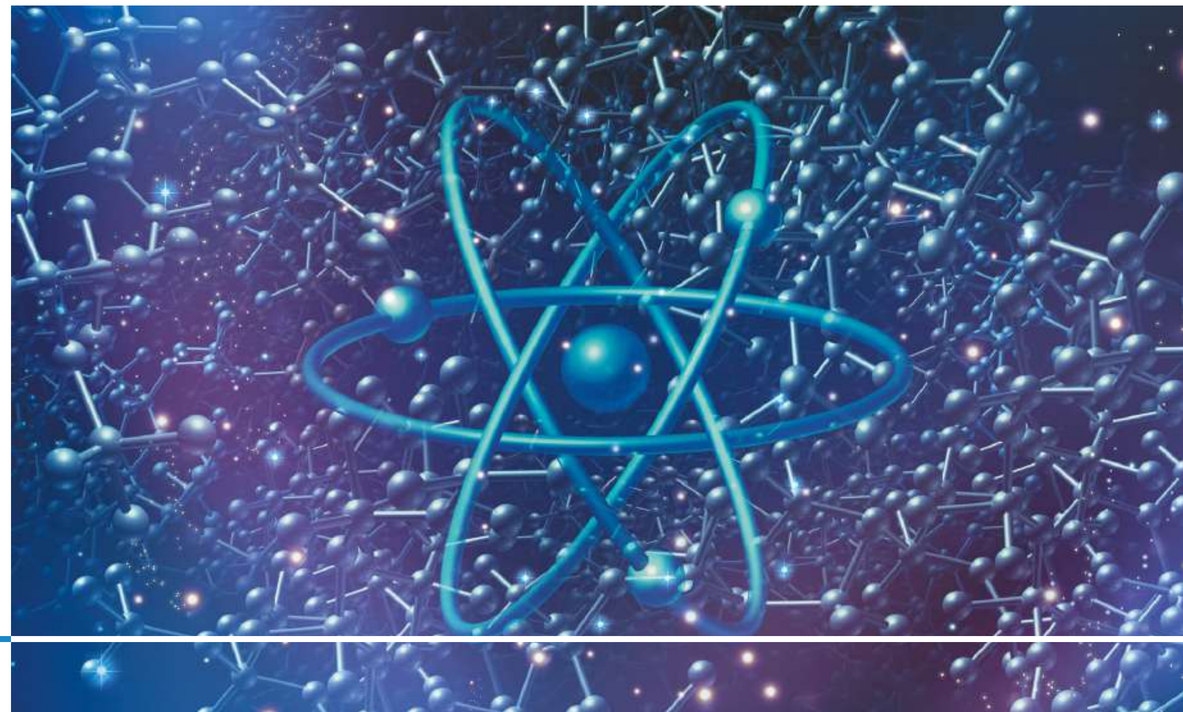
$T_e = 86{,}161.54933185$ s – period of the Earth's rotation around its radial axis;

ρ0= 1.25 kg/m3– atmospheric density at the Earth's surface;

$V_1 = \sqrt{\dfrac{G \times M_{Earth}}{R_e + 415}} = 7{,}660.045$ m/s – required orbital velocity, for a circular orbit with a height of 415 km.







Parameters being set:

$$E_{el} = \begin{pmatrix} 206 \\ 206 \\ 137.3 \end{pmatrix} \text{GPa – Young's modulus of the GPV's elements;}$$

$$S_{el} = \begin{pmatrix} 0.057 \\ 0.026 \\ 0.064 \end{pmatrix} \text{m2– cross-sectional area of the GPV's elements.}$$

For the modelling process, Young's modulus of the fl wheels was chosen as the modulus of the steel. For the housing, the modulus was chosen in accordance with GOST 10994-74 "Precision alloys. Grades", alloy H36 "Invar" [2]. Invar alloy has a lower modulus of elasticity, a large relative elongation before rupture and a low value of thermal expansion in comparison with the steel alloy. These parameters make Invar a suitable choice for the rotor housing and the given requirements. Based on the given values, the linear stiffness of the GPV segment C_{GPV} can be calculated as:

$$G_{GPV} = \frac{1}{L_{GPV}} \sum_i \left(E_{el_i} \times S_{el_i} \right) = 0.548 \text{ KN/m.}$$

Mass parameters of the system were calculated to achieve the optimal mass ration of the rotors and the housing. The values were chosen based on the consideration of the efficiency of the linear electric mot , which is equal to 95 %.

$$m_{el} = \begin{pmatrix} 450 \\ 200 \\ 500 \end{pmatrix} \text{kg – mass per unit length of elements (rotor 1, rotor 2, housing).}$$

Relative initial rotor take-off velocities: $V_{r.0} = \begin{pmatrix} 12.55 \\ -0.1 \\ 0 \end{pmatrix}$ km/s.

Absolute initial rotor take-off velocities: $V_{a.0} = \left(V_{r.0} + \omega_1 R_0 \right) = \begin{pmatrix} 13.015 \\ 0.365 \\ 0.465 \end{pmatrix}$ km/s.

Developed model also includes the mass dropping (dead weight) control function and the frictional expansion control, which is based on the Maxwell model with adjustable expansion resistance (Figure 4).

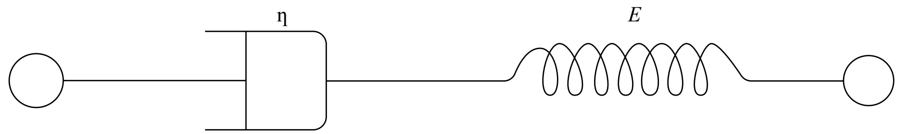


Figure 4 – Maxwell model for a visco-elastic damper.
The viscous damper is connected in series with an elastic spring

Forces, acting on the GPV element during take-off, were calculated as follows

- rotor centrifugal force:

$$F_{r.r} \left(h, V_{el} \right) = \sum_i \left[m_{el_i} \left(V_{el_i} \right)^2 \frac{1}{\left(R_0 + h \right)} \right];$$

- gravity force:

$$G_i \left(h \right) = m_{GPV} \frac{g R_0^2}{\left(R_0 + h \right)^2};$$

- longitudinal force in the ring:

$$F_{c.\tau} \left(h, \Delta L_d \right) = C_{GPV} \left(2\pi h - \Delta L_d \right);$$

- elasticity radial strength in the ring:

$$F_{c.\tau} \left(h, \Delta L_d \right) = \frac{l_i}{L_{GPV}} F_{c.\tau} \left(h, \Delta L_d \right);$$

- aerodynamic resistance due to atmosphere:

$$Q_{atm} \left(V, h \right) = c_d \left(d_0 l_i \right) \frac{V^2}{2} \rho_0 e^{-\frac{h}{7.64 \text{ km}}};$$

- linear motor thrust:

$$F_{le} \left(V, t, i \right) = \left| k_v \left(t \right)_i \min \left(\left| \frac{W_{le}}{V} \right|, F_{\max} \right) \right|.$$

Based on the parameters presented above and the first iteration of the calculation, the following system of equations was obtained.

Radial motion equation:

$$F_{r.r}\left[h(t)\begin{pmatrix}V_1(t)\\ V_2(t)\\ V_{sh}(t)\end{pmatrix}\right] - G_i\left(h(t)\right) - F_{c.r}\left[h(t),\Delta L_d(t)\right] -$$
$$- Q_{atm}\left[h'(t),h(t)\right] - M(t)h''(t) = 0.$$

Kinetic momentum change equation:

- for rotors:

$$F_{le}\left[V_1(t)-V_{sh}(t),\, t,\, 0\right]\left[R_0+h(t)\right]-m_{r_0}\left[V_1(t)h'(t)+V_1'(t)\left[R_0+h(t)\right]\right]=0;$$

$$F_{le}\left[V_2(t)-V_{sh}(t),\, t,\, 1\right]\left[R_0+h(t)\right]-m_{r_1}\left[V_2(t)h'(t)+V_2'(t)\left[R_0+h(t)\right]\right]=0;$$

- for the shell:

$$\left[F_{le}\left[V_2(t) - V_{sh}(t),\, t,\, 0\right]\right] + F_{le}\left[V_2(t) - V_{sh}(t),\, t,\, 1\right]\left[R_0 + h(t)\right] +$$
$$+ m_{sh}\left[V_{sh}(t)h'(t) + \frac{d}{dt}V_{sh}(t)\left[R_0+h(t)\right]\right] = 0.$$

Frictional expansion equation:

$$\frac{\eta}{l_i}\left(\frac{d}{dt}\Delta L_d(t)\right) - k_d(t)F_{c.\tau}\left[h(t),\Delta L_d(t)\right]=0.$$

Initial boundary conditions of the task:

$$h(0) = 0;\; h'(0) = 0;$$
$$V_1(0) = V_{a.0_0};\; V_2(0) = V_{a.0_1};\; V_{sh}(0) = V_{a.0_2};$$
$$\Delta L_d(0) = 0.$$

7.3 Results and Analysis

Based on the solution of the systems of equations and from the developed mathematical model, the dependencies (Figure 5), were collected.

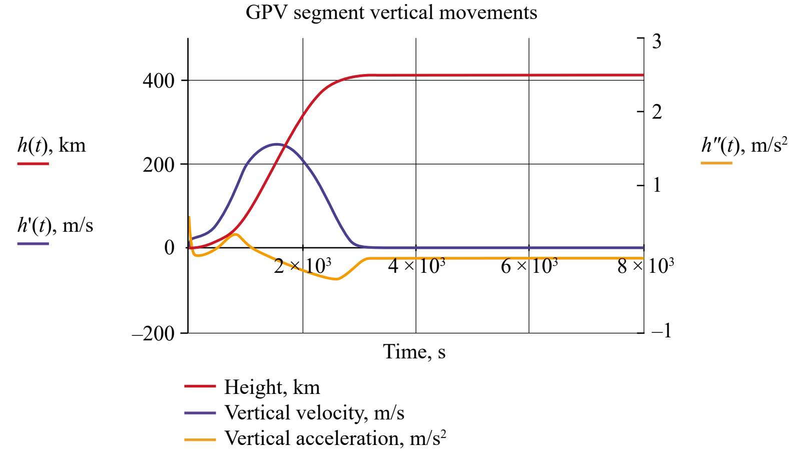


Figure 5 – Diagram of ascend, vertical velocity and vertical acceleration with time

The diagram in Figure 5 shows that the GPV rises to the given height (415 km above the level of the World Ocean) and is achieve stable conditions within it. The maximum vertical acceleration of the housing during take-off is 0.33 m/s2, the horizontal average acceleration (peripheral around the Earth) is 2.04 m/s2(time of ascent to orbit is 6.8 × 10^3 s (Figure 7).

To achieve the flight stability and steady-state positioning on a desired orbit, various techniques and options were used. From the point of view of feasibility, the most optimal solution was the process of sequential transfer of energy from one flywhee to another. The relative velocities of rotors during take-off (in relation to the GPV housing) and absolute velocities of the GPV elements during take-off are shown in Figures 6, 7.

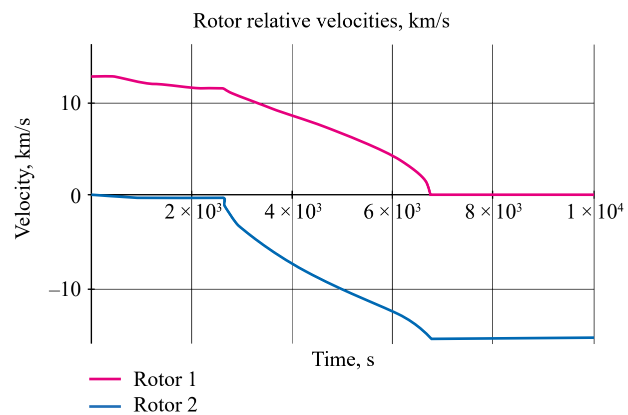


Figure 6 – Velocities of rotors during take-off (in relation to the GP housing)

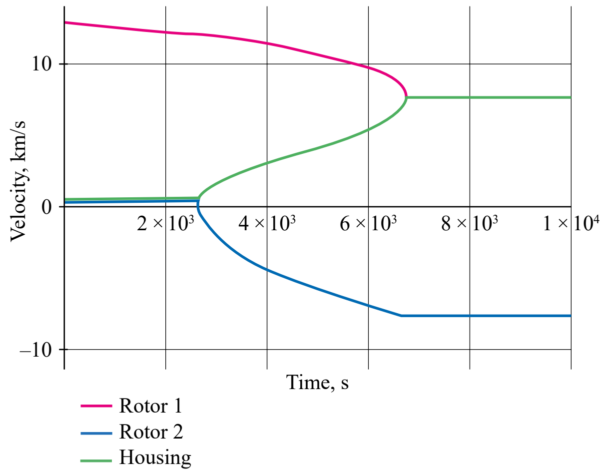


Figure 7 – Absolute velocities of GPV elements during take-off

Upon reaching a given orbit, the velocities of all the GPV's elements (the housing and two flywheels) must be equal to the given Earth's orbital velocity for the given height (7,660 m/s) in the direction of the Earth's rotation or in the opposite direction. In the process of kinetic energy transfer from one flywheel to another, a loss of energy occurs in the linear motors leading to the GPV destabilization (Figure 8).

The cumulative losses of the energy transfer process are equal to 1.148 GJ per metre length. To stabilize the GPV ring, the compensation of this energy is necessary. At this stage, hydrogen is supposed to be used to stabilize the scheme and supply energy. The calorific value of hydrogen is about 140 MJ/kg. If we assume that the efficiency rate of a hydrogen fuel cell is about 50 %, then for each metre of the ring, 16.4 kg of hydrogen will be required. It can be part of the ballast which should be loaded into the GPV cargo compartments.

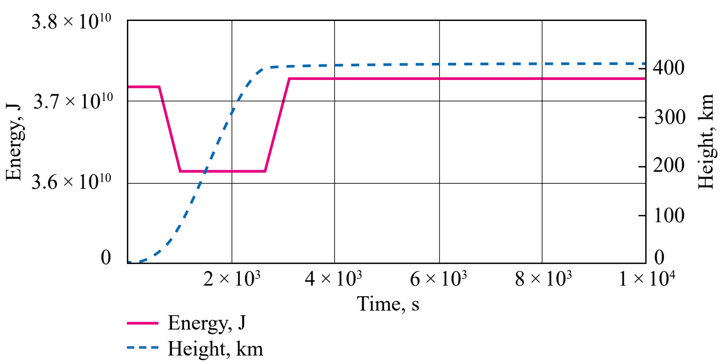


Figure 8 – Diagram of the full GPV mechanical energy in time

Further development and optimisation process includes the use of a jet blast from a cryogenic fluid as a power source and as a ballast. Such liquid substance can be heated up in the process of cooling of the drivetrain system. For this purpose, it is permissible to use, for example, nitrogen or oxygen, cooled to the temperatures of about −200 °C. These gases can be released into the atmosphere in the form of a jet blast without any significant pollutions. Eventually, oxygen solution has capability to partially restore the ozone layer (in the oxygen option).

To accelerate the flywheels to the required starting velocities, 1.42×10^{18} J of energy is required. To accelerate the 450 kg/rm rotor to the required velocity of 12.55 km/s in 20 days, the electric motor of 21.6 kW/rm is required. As the acceleration time increases, the required power decreases.

Diagrams of the generated (due to the regeneration) and consumed power during take-off are shown below in Figure 9, and the function of power on/off control at rotor drives during take-off is shown in Figure 10

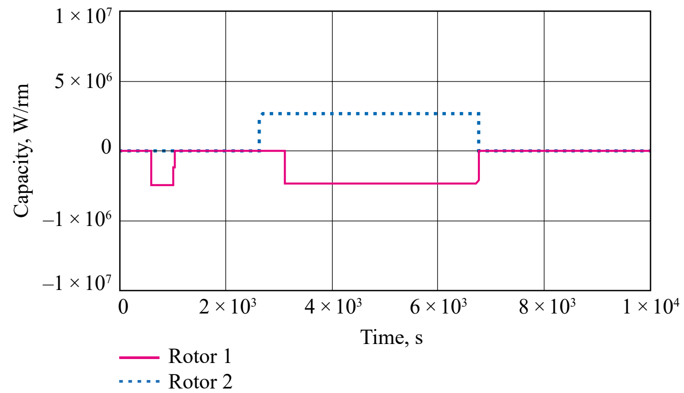


Figure 9 – Diagram of power consumed during take-off, W/rm

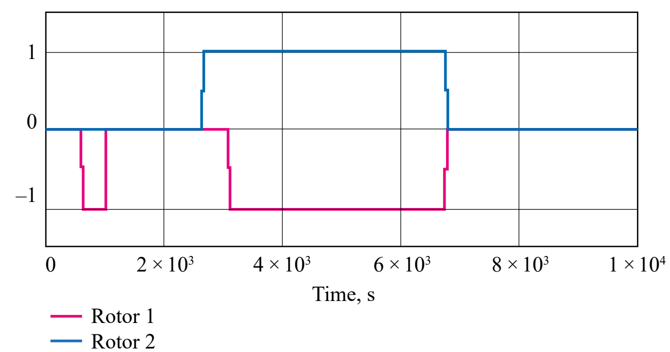


Figure 10 – Function of power on/off control on rotors during take-o

One more diagram should be drawn as a conclusion – the diagram of system energy changes during take-off (where the total energy loss of the system is also visible), from which efficiency can be calculated (Figure 1).

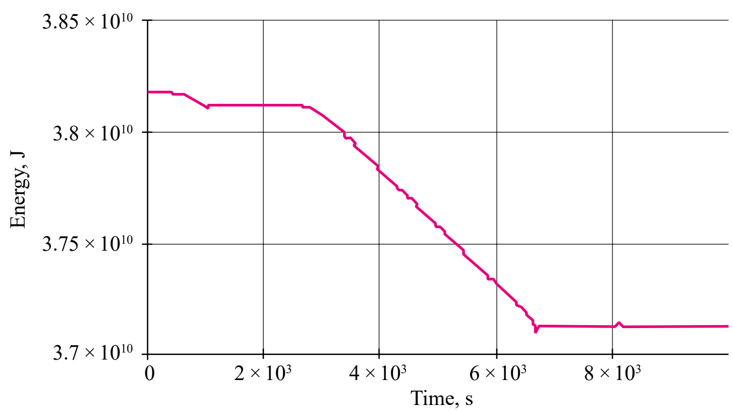


Figure 11 – Diagram of change in the total system energy during take-off

As it can be seen, energy losses during the GPV take-off do not exceed 2.8 %, and taking into account the losses during the initial acceleration of the rotor (when the efficiency rate o linear electric motors is 95 %), the total amount of losses will not exceed 7.6 %.

Comparison of options of different arrangements, i.e., different ratios of flywheel masses and linear motor efficienc rates is given in Table 1. Based on these data, it is possible to estimate the difference in the initial velocity, the total actual efficienc rate of launching into orbit and the need for additional energy for stabilization during take-off

As it can be concluded based on the results, the best option is the option No. 4, which was considered in this paper: in terms of the starting velocity of the flyw eels

Table 1 – Comparison of options of different GP arrangements

Option number	Mass of GPV, rotor 1 / rotor 2 / housing, kg/rm	Linear motor efficienc rate, %	Initial velocity of rotor 1, km/s	Efficienc rate of launching GPV into orbit, %	Need for additional energy at launching GPV into orbit, GJ/rm
1	250/225/500	90	15.65	92.4	2.43
2		95		96.3	1.16
3	450/200/500	90	12.55	94.4	2.27
4		95		97.3	1.16

(which is lower than in the option with lighter flywheels), as well as in terms of the efficienc rate of launching the GPV to a low near-Earth orbit. In addition, it requires less energy to stabilize than other options. We would especially like to emphasize that the vehicle's level of effi ency for that system is 97.3 %, this value favourably distinguishes the considered project from any kind of geocosmic transport available today to humanity.

7.4 Dynamic Optimisation

A. Feasibility Study of the GPV Displacement in Relation to the Equator

As it was presented above, the GPV routing was designed in the only possible location – along the equator. As a result, its overpass has to cross two significant regions with the vertical elevation being presented:

1. The Andes mountains (Figure 12);
2. Mountain area in Kenya (Figure 13).

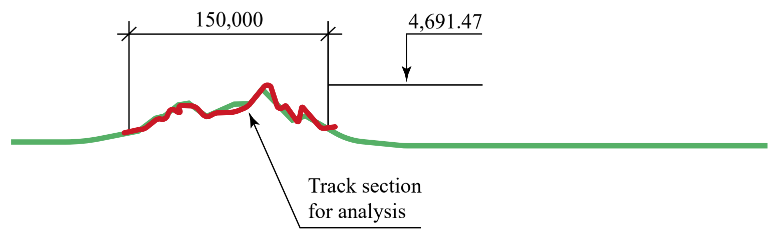


Figure 12 – Mountains in South America (values given in metres)

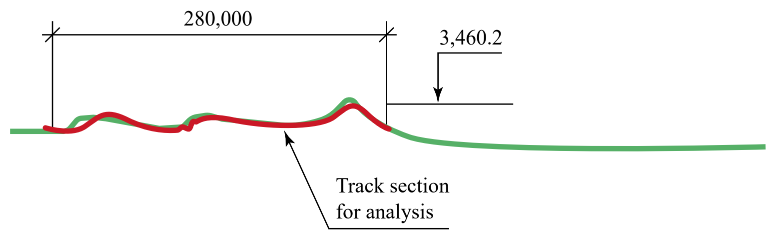


Figure 13 – Mountains in Africa (values given in metres)

The structures were assessed in accordance with finite-element modelling principles.

It is impossible to optimise displacement of the GPV track route in the equatorial plane due to the following obstacles. The first obstacle is the need in substantial displacements of the GPV track to efficiently bypass vertical obstacles, which generates additional forces, acting on the structure (Figure 14).

Red line in Figure 14 is the equator line, blue line – the GPV ring with the required displacement. Force F_1, which effect cannot be negated by the system, acts in plane of the GPV. During take-off, the structure tends to attain equilibrium state, shifting to the equatorial plane. However, due to the accumulation of inertial components, at reaching equatorial plane, the structure crosses the targeted plane and continues its motion, but at a smaller distance (at initial displacement not more than 50 km in relation to the equator) towards the opposite side of the oscillation process. With such motion, the GPV structure, after several cycle of such fluctuations, will be able to reach equilibrium state. If the distance exceeds 50 km, the structure during take-off will fall into one of its global frequencies, enter the state of resonance and begin to swing itself, which is unacceptable as it significantly increases the risk of the collapse.

The second obstacle arises from the fir t condition. Displacement less than 50 km with respect to the equator plane does not generate any signifi ant effects due to the fact that the number of obstacles to be overcome decreases.

Accordingly, based on the above analysis, it can be concluded that the displacement of the GPV structure relative to the equator is impractical. Thus, it is necessary

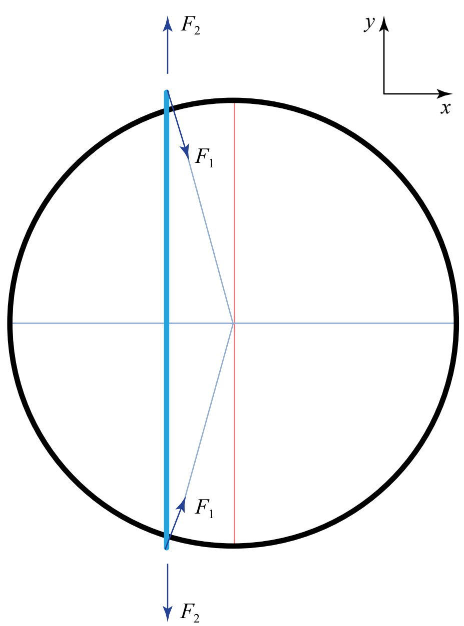


Figure 14 – Diagram of action of vertical lifting force F_2 and additional force F_1, resulting during displacement of the GPV structure relative to the equator

to overcome the obstacles that arise when laying the GPV overpass along the equator (Figures 12, 13).

B. Assessment of Feasible Options of Bypassing Vertical Obstacles

Firstly, the basic principles at the core of the developed methodology for overcoming obstacles were considered and optimised. Figure 15 presents an idealized scheme for bypassing a conditional mountain. Using the model, values of forces were obtained arising during construction at similar radii of curvature of the trajectory of the GPV's rotors.

Diagram is shown in Figure 15 with both axes representing distances – vertical at y-axis and longitudinal – on x-axis. Units of measuring – metres for absolute trajectory, millimetres – for relative displacement. Red-marked lines are absolute values of obstacle bypassing, blue-marked line demonstrates relative movements of the linear flywheel inside the body of the GPV, increased by four orders to visualise the vertical movements. With such motion diagram, the trajectory curvature radii can be summarised in Figure 16.

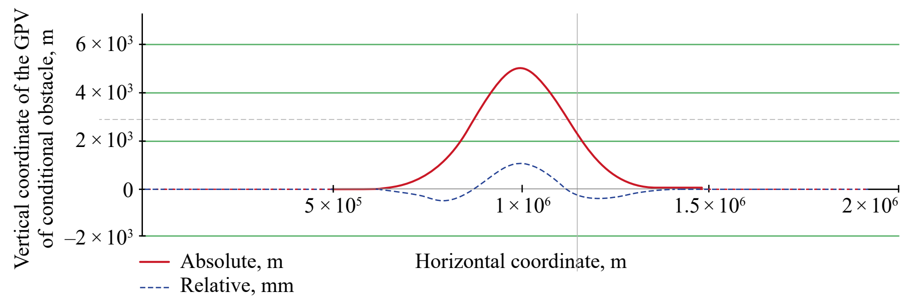


Figure 15 – Conditional obstacle, described by the trajectory of exponential function

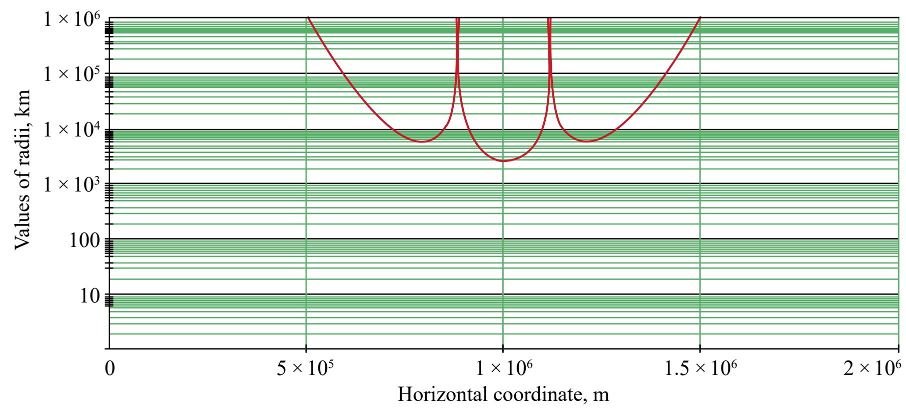


Figure 16 – Diagram of trajectory of curvature radii during passage of a conditional obstacle

In this case, the minimum acceptable radius of curvature comes as 2.778×10^3 km (minimum factor of radii). This value of radius does not cause a system response to resonance frequencies, even considering the dense spectrum of the GPV. Frequencies spectrum is given in Figures 17, 18.

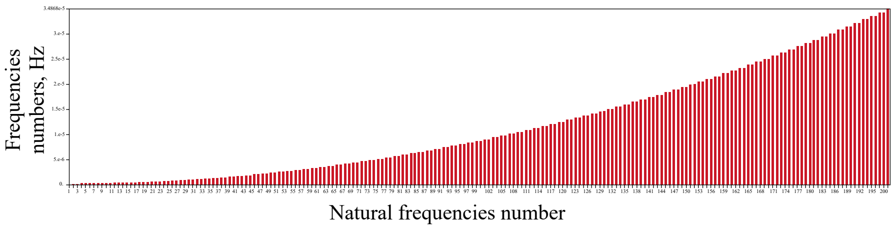


Figure 17 – Distribution of the first 200 frequencies of the st ucture (flywheel at maximum initial speed

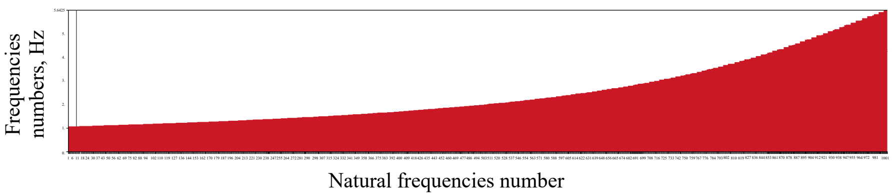


Figure 18 – Distribution of 1,000 of frequencies after 1 Hz (flywheel at maximum initial speed

Visual representation of possible oscillations is given in Figure 19.

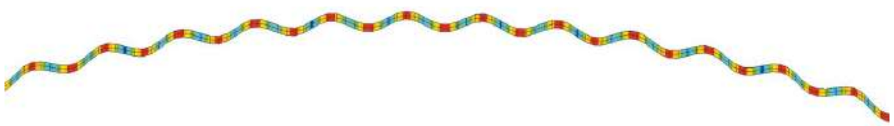


Figure 19 – Visual representation of flywheel natural oscillation frequencie .
Deformations (range of irregularities) are increased by 10,000 times

When accumulating the modal mass, the natural frequencies of the fl wheel accumulate the number of waves in the shape of which oscillations occur. Within 10,000 frequencies, no mode was found that is significantly different from the above mentioned.

The first 20 frequencies are given in Table 2.

By the time the flywh el enters the trajectory of motion along the obstacle, these frequencies are becoming even more dense, which negatively affects the passage of radial sections and the GPV stability. If the trajectory radii are insufficient the graph of relative rotor oscillations will converge to the line, presented in Figure 20 with the forces factors summarised in Figure 21.

Table 2 – First frequencies of natural oscillations of the structure

Mode	Frequency, Hz
1	3.22×10^{-8}
2	8.49×10^{-8}
3	1.47×10^{-7}
4	1.61×10^{-7}
5	1.85×10^{-7}
6	2.05×10^{-7}
7	2.12×10^{-7}
8	2.28×10^{-7}
9	2.37×10^{-7}
10	2.41×10^{-7}
11	2.54×10^{-7}
12	2.68×10^{-7}
13	2.76×10^{-7}
14	3.01×10^{-7}
15	3.09×10^{-7}
16	3.42×10^{-7}
17	3.54×10^{-7}
18	4×10^{-7}
19	4.12×10^{-7}
20	4.66×10^{-7}

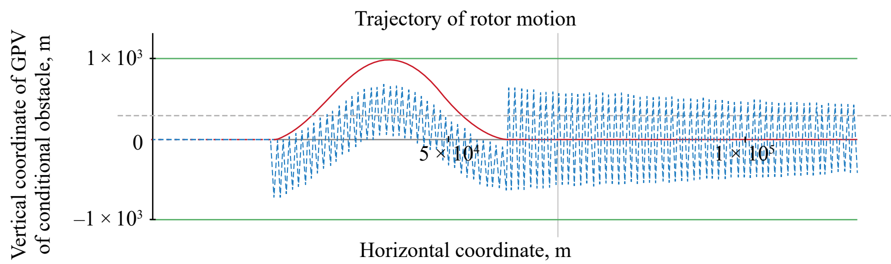


Figure 20 – Graph of flywheel oscillations in magnetic field of PV suspension
systems in case of non-fulfillment of radii conditions on spira curve

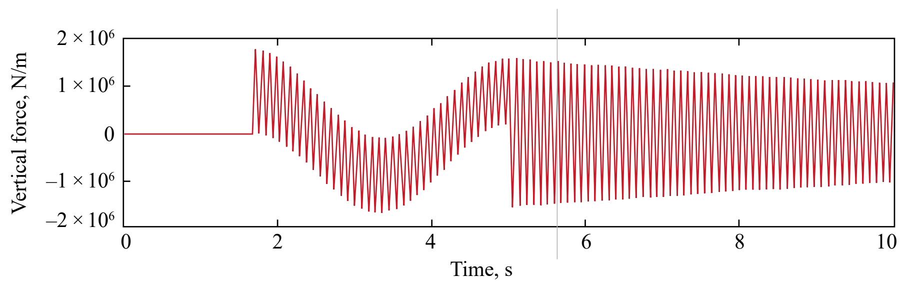


Figure 21 – Graph of flywheel forces, in case of non-fulfillmen of radii conditions on spiral curve

As can be seen in Figures 20, 21, minimum radius deviation or tough transition at any of the trajectory sections will result in the force impact and it might fall into one of the system's natural frequencies. The amount of forces created by such deviation reaches 1.8 MN/m, which will inevitably lead to the destruction of the body and the entire the GPV structure. It follows therefrom that the accuracy of calculating and selecting the trajectory of motion (rotation around the planet) of the fl-wheels inside the GPV body plays a pivotal role. If the requirements for radii are met, the transverse force graph will be changing according to the function presented in Figure 22.

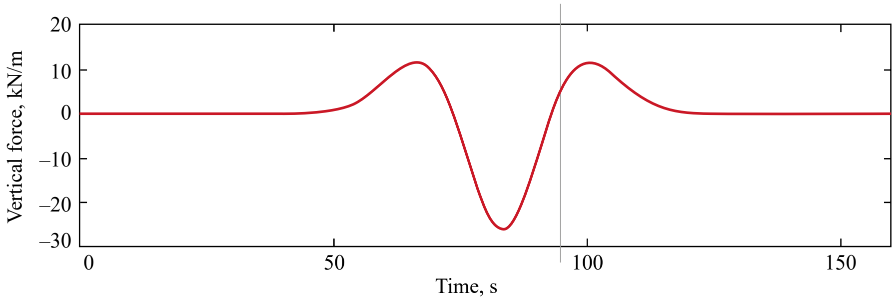


Figure 22 – Graph of forces at optimal passage of irregularities

Values of forces for the optimal trajectory motion do not exceed 25.9 kN/m, which is acceptable value for the structure and its strength values. As the curves radii of the flywheel trajectory increase, the vertical forces in these areas will decrease proportionally.

The optimal equation depicting the trajectory of the flywheel in the GPV structure can be presented by the equation:

$$f_{\exp}(x) = H_1 \times e^{\frac{-\left[6(x-L_1)\right]^2}{L_1^2}}, \qquad (1)$$

where H_1 – the height of an obstacle;

L_1 – total length of an irregularity in plan.

If vertical curves of the GPV structure, when passing along the trajectory, meet the pattern given in formula (1), there will be no excessive transverse forces. Furthermore, oscillations of the flywheel of the GPV will also be negligible, considering magnetic support of the system.

After the track profile is formed, the issue of take-off process of the GPV structure arises. As can be seen from Figures 17, 18, a dense spectrum of frequencies is observed both on the global design scale and locally. While the GPV is on the overpass, as regards to the general structure of the ring, a dense spectrum of frequencies does not play an important role when meeting the requirements for radii.

After take-off, the structure has only the actual bending rigidity of the ring and the gained dynamic rigidity due to the high speed of rotation of the flywhee around the planet. Actual stiffness was obtained by numerical methods using finite-element simulation. The stiffn ss of the ring, when it is brought into general composition, is 2,500 kN/m. This is extremely high bending stiffness, given the small transverse dimensions of the flywheels relative to the size of the planet – less than 1/10,000,000.

At the moment of the beginning of the lift-off, the structure tends to attain the most favourable position for itself – a clear circular trajectory. When flattening occurs, the system gains forces directed not from the geometric centre of the system, but from the geometric centres of the curves inscribed in the track of passing by the obstacle (Figure 23).

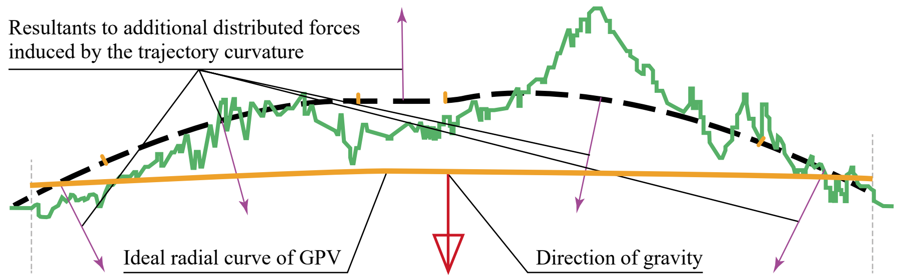


Figure 23 – Optimised scheme of passing by the Ands

In Figure 23, a black dashed line shows the curve of the passage of the GPV through the Andes in the equator plane (option). As can be seen, the resultants to distributed forces before the liftoff of the GPV are scattered and directed to their individual centres. When taking off, this creates local multiple angular deviations of forces relative to the lines of action of gravity directed to the centre of the Earth. Those angular deviations induce bending moments and, accordingly, to excitation of several natural frequencies at once. At the cosmic velocity of the flywheel inside the magnetic field, frequencies begin to appear one after another and overlap each other. One example of this overlay is shown in Figure 24.

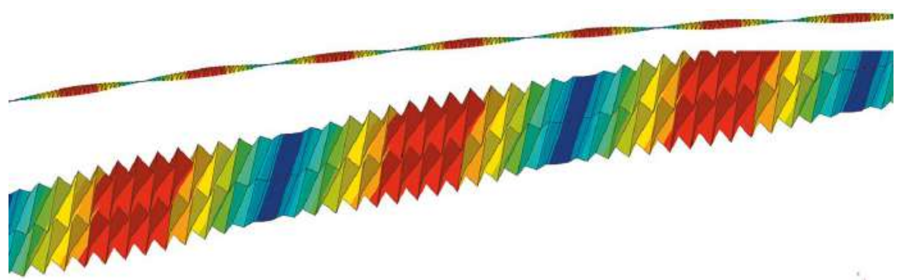


Figure 24 – Options for possible frequency overlay

The solution of the take-off problem consists in prevention of infl ction of the GPV structure due to moment load at the moment of detachment of the GPV from the overpass. The deflection that occurs during the lifting process can, for example, be compensated by the local release of the ballast, or by the corresponding uneven loading of the ballast along the length of the GPV prior to the start. The damping of these eff cts during stabilization is achieved, for example, by jet stream calculated from the value of thrust at 0.87 kN per running metre, with an increase in this value to 2.61 kN/m to the edges of the curves. In this case, the take-off diagram changes to the curve reflected in Figure 5. It was obtained based on the general theory given in [3] and [4]. However, the same can be initially compensated for by increasing the radii of curvature of the GPV in areas passing through the mountains, by performing deep excavation of rocks in the highland areas and erecting high supports in the foothills. However, this requires a separate optimisation that goes beyond the scope of this study.

7.5 Conclusions and Future Work

Based on the performed analysis, it is possible to draw the following conclusions.

- Mountains and other possible areas where the track has to be bent include traversable obstacles and do not pose problems to the flywheels acceleration to the cosmic velocities. Under defined conditions of the flywheel trajectory and under the transverse influence of compensating force, for example, by jet (turbojet) engines, a smooth and stable take-off of the entire GPV structure on the mountain sections of the take-off and landing overpass can be ensured
- Plane-parallel displacement of the take-off and landing overpass of the GPV relative to the equator plane does not yield tangible results when optimising the passage of mountain sections, but causes a large number of design difficulties for lateral stabilization.

In the future, it is planned to simulate the take-off of the structure on the basis of already known obstacles, taking into account the dynamic factors researched in this study, and considering the actual magnetic field of the Earth, as well as validation of stabilization and coupling of the GPV with a circular orbital station seizing the planet in the equator plane.

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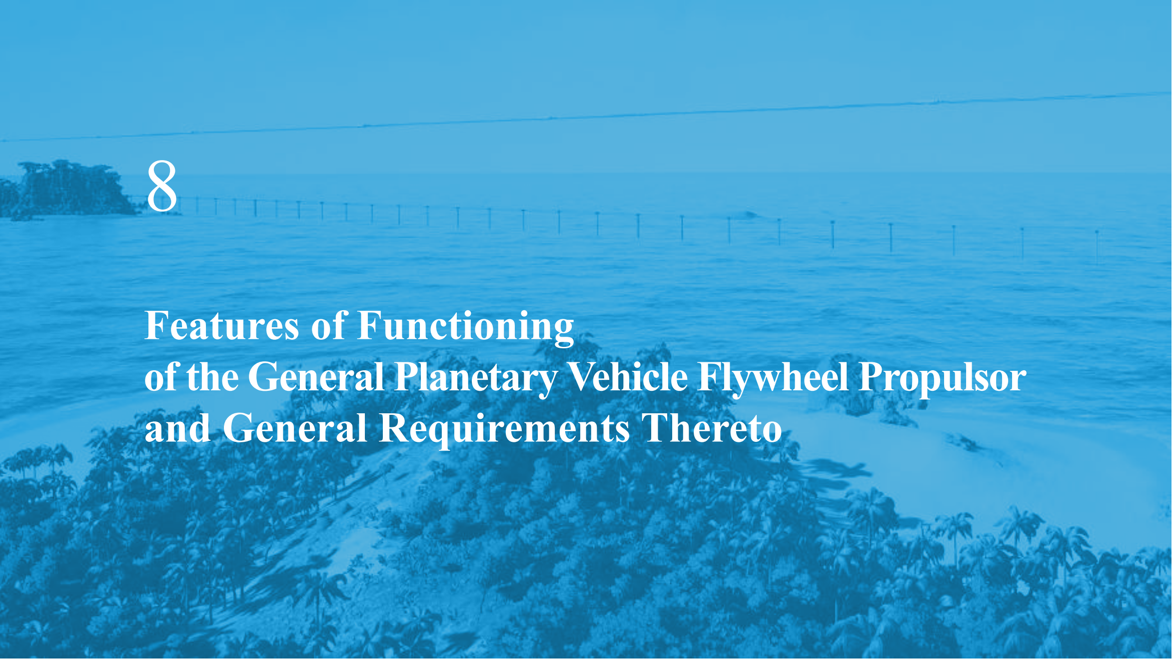


8

Features of Functioning of the General Planetary Vehicle Flywheel Propulsor and General Requirements Thereto

8.1 Introduction

From the standpoint of fundamental physics, the most energy efficien and environmentally friendly geospace aircraft should use for entering the space only its own internal forces. The only way to comply with this requirement is a ring structure around the Earth in the equatorial plane, with its centre of mass coinciding with the Earth centre of mass and that does not change its spatial position when entering orbit [1]. The body of the General Planetary Vehicle (GPV) by engineer A. Unitsky [2] is a torus encircling our planet in the equatorial plane (Figure 1). Outside the GPV body, gondolas with cargo and/or passengers are attached, and inside it there are magnetic suspended belt flywheels driven by linear electric motors in forward and reverse directions.

The GPV belt flywheels linear drive system design is in many respects similar to the design of the electric train magnetic levitation and traction systems. There are three schemes for using a hybrid technology of magnetic suspension and a linear synchronous motor [3].

One of three known types of hybrid technologies is an electrodynamic suspension (EDS) with superconducting magnets on board the rolling stock. These magnets being cryogenic cooled conduct electricity even after disconnecting the power source. The rolling stock rests on the roadbed, but the repulsive force of the magnetic field

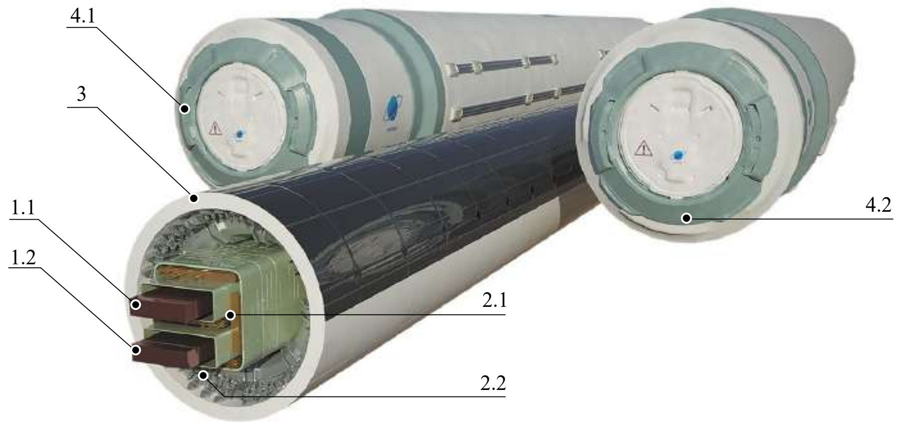


Figure 1 – GPV design: 1.1 and 1.2 – belt flywheels;
2.1 and 2.2 – magnetic suspension systems and linear electric motor;
3 – body; 4.1 and 4.2 – containers with cargo (visualisation) [2]

forms a gap that excludes their contact with each other. Such a system is self-stabilizing – as the gap decreases, the repulsive force of the magnetic field increases and returns the system to the previous gap. Consequently, the EDS suspension technology does not need any sophisticated electronics to provide a safe gap, which can reach tens of millimetres, just as onboard batteries are not needed to maintain a magnetic field, in particular at stops. On the basis of the considered technology the Japanese JR-Maglev trains were built [3].

There is one more type of the EDS suspension technology that has not yet been implemented in commercial practice – using permanent magnets that do not require either electricity or cryogenic cooling [3]. Permanent magnets do not have sufficie strength to levitate rolling stock, but their special placement in the so-called Halbach array allows the formation of a much stronger magnetic field, directed not in both, but all to one side from the array.

Also, it is known the technology of electromagnetic suspension (EMS) with electromagnets on board the rolling stock, with which it is suspended from below to the edges of the T-shaped roadbed [3]. The disadvantage of the analysed structure is that it is not stable – with an increase in the gap, the force of attraction decreases, and without an external control action that creates the required large force of attraction, the system itself cannot return to the required gap. The EMS suspension technology requires on-board electric power batteries to provide continuous power to the electromagnets during shutdown periods. On the basis of this solution, Transrapid trains, in particular Shanghai Maglev [3], were built.

The systems of a linear electric motor in magnetic levitation trains both for the EDS and EMS technologies are fundamentally similar – it is a synchronous linear electric motor, because it allows a relatively large gap, which provides a 95 % and higher efficien . The roadbed is a conventional stator deployed in a line, and the supporting magnets of both types of magnetic suspension systems, located on board the rolling stock, simultaneously act as an anchor for the specified linear synchronous motor. To our attention, so-called hybrid scheme of a magnetic suspension and a linear electric motor with improved weight-size and energy performance characteristics are presented.

However, due to a number of specific requirements and operating conditions, the GPV levitation and flywheel drive systems will be much more complex and unique than the magnetic levitation trains.

8.2 Features of the GPV Flywheel Propulsor and General Requirements Thereto

In the case of the GPV, the magnetic suspension system, as well as the magnetic levitation train drive, is designed to exclude the contact of the moving belt flywheel with the linear components of the GPV structure, primarily with the walls of the vacuum channel. At the same time, the design of a geospace vehicle with a length of 40,000 km and a mass of about 40 mln tons imposes some specific requirements.

Let us consider schematically the phases of the geospace flight of the GPV from the Earth's equator to the low equatorial orbit [3]. During the prelaunch stage of geospace fl ght, being on the take-off and landing overpass, the fl wheel accelerates to speeds of 10–12 km/s, exceeding the fir t cosmic velocity (7.9 km/s). The lifting force created by the rotation of the belt flywheel around the planet is directed from its centre, i.e., vertically upward at each point of the equator, and must exceed the force of gravitational attraction. Such an excess of the lifting force (for simplicity, it is given below specified to each running metre of the GPV length) depends on many factors: the height of further lifting height (the higher the given orbit is positioned, the greater the lifting force excess should be), the efficienc of the electric drives of the belt flywheels and other upcoming energy losses during the flight, in particular, aerodynamic drag in the atmospheric section of movement and energy losses associated with the discharge of ballast and other changes in the total flight mass. These factors, along with other conditions, are discussed in more detail below. To avoid involuntary lifting, the body must be fixed with special locks along the entire length of the overpass.

In the first phase of the flight (after the simultaneous opening of the locks along the entire length of the overpass), the GPV will start to rise to a given orbit height with gondolas fixed to its body, filled with passengers and cargo. In this case, the diameter of the GPV toroidal body will increase in size – from initial values equal to the equatorial diameter of the Earth, to final values equal to the diameter of near-Earth orbit towards the flight is made. So, the GPV will deliver the cargo to an altitude corresponding to the placement of a low near-Earth circular orbit.

An indispensable condition under which the cargo can be considered delivered to a circular orbit, is its rotating around the planet at the first cosmic velocity,

since only in this case it becomes an artificial satellite of the Earth and can be left there in a free orbital flight (weightlessness). That is why, during the second stage of the GPV flight, the flywheel begins to be decelerated by its linear motor, which has switched to the generation mode. The GPV body with the weights fixed thereon at the same time receives an impulse in the direction of the flywheel movement, smoothly increasing the speed of its rotation around the planet until it reaches the first cosmic velocity specified for an altitude of the given orbit

The first and second phases of geospace flight are carried out simultaneously according to a special programme per the route assignment, which is compiled for each flight, taking into account the weight load, external conditions on the atmospheric section of the route (air temperature, wind, precipitation, etc.) and other factors. The return of the GPV to Earth is performed in the reverse order.

Another (second) belt flywheel is needed to effectively transfer momentum and angular momentum between the belt flywheels and the body structure and cargo on it. The deceleration of the first flywhe l is carried out due to its linear motor, which has switched to generator mode. In such a case, the released energy cannot be discharged into the environment, but is used to accelerate the second belt flywheel. Its acceleration in the opposite direction will provide not only effective energy recovery, but will also transmit a double impulse to the GPV body and cargo on it. Only in this way could be archived the maximum efficienc and high overall efficienc while performing a cargo lifting from the Earth to near-Earth space and spinning around the Earth to an appropriate to orbit first cosmic veloci y.

The mass of the two belt fly heels should be sufficient in order for the GPV to accumulate inside, at initial (obtained on Earth) speeds of 10–12 km/s, not much higher than the first cosmic velocity, the energy, momentum, and angular momentum reserve for the launch to orbit only due to the internal forces of a closed system, without any forceful interaction with the environment.

Considering the cosmic velocity of the belt flywh els and the inadmissibility of their friction against the air during the GPV fl ght in the lower dense layers of the atmosphere, they must be isolated inside the vacuum channels with a safe gap from the walls.

Features of functioning associated with the lengthening of all linear components of the GPV structure (body, magnetic levitation system, linear electric motor, etc.) by 1.57 % every 100 km of rise above the Earth's surface, impose one more essential requirement – to ensure there is constructive possibility of lengthening up to 6.5 % (for the case of rise at a near-Earth orbit with an altitude of about 400 km). A fundamental approach to provide this requirement is the linear segmentation of the entire GPV structure and systems using two types of segments: basic functional with constant length (first type), which, with a certain step, will be separated by special extendable segments (second type), also carrying communication lines of all onboard GPV systems, including power and communication lines.

The most difficultie in solving the elongation task are caused by the GPV body, vacuum chambers, magnetic levitation, and linear electric drive systems, as well as two belt flywheels, which have linearly continuous design and bear tensile force load.

This means that their elongation could be provided either on the basis of elastic structures (including bellows, flat and plate springs), or due to movable joints. At the same time, belt fly heels can be assembled without the use of special elongated segments and increase in their linear dimensions only due to the elastic properties of special materials, including superconducting composites and permanent magnets. As for magnetic levitation systems and linear electric motors, their segmentation does not seem particularly difficul since the division into segments will be similar to the movement of several trains along a common circular route.

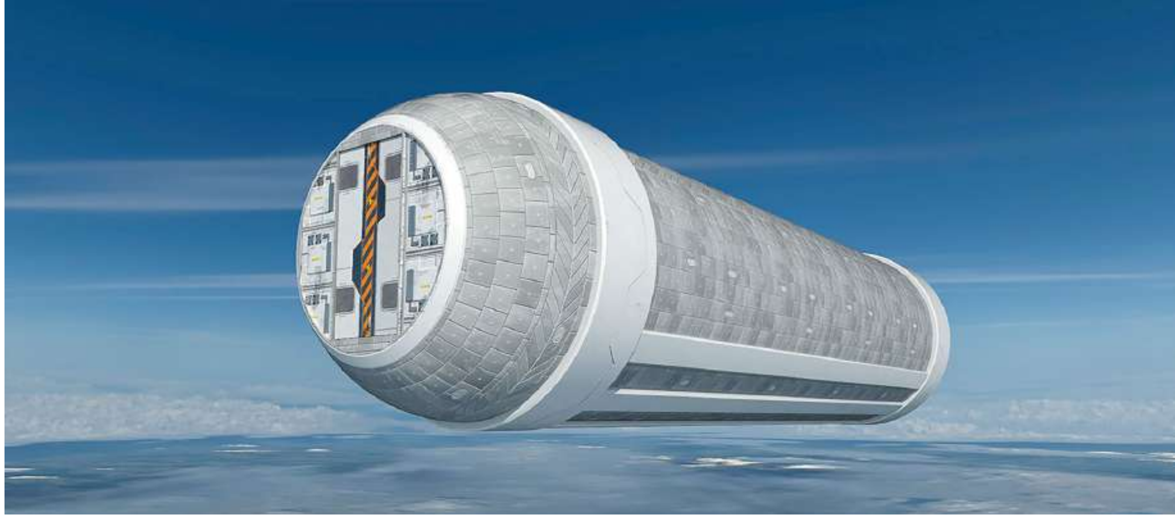
Taking into account such important requirements for any aircraft like the lightness and reliability of the design, the most suitable magnetic levitation system and a linear electric motor to drive belt flywheels is the EDS self-stabilizing electrodynamic suspension technology using superconducting magnets cooled to cryogenic temperatures. At the same time, provided that the rotating belt flywheels move at speeds exceeding the first cosmic one and cannot be used to accommodate other complex systems, and that direct commutation with them is impossible, superconducting magnets with a cryogenic cooling system must be located on the side of the GPV body structure, where all the onboard functional devices are located.

In the light of the fact that the gigantic kinetic energy is contained in hyperspeed belt flywheels with a mass of millions of tons, notwithstanding the highest energy efficienc of GPV thanks to its design, from the standpoint of fundamental physics, anyways, there will be losses in the GPV electrical systems. Therefore, it is important to ensure the highest energy efficiency at a 99 % level, which is possible for m dern electrical systems [4]. Such a solution will make it possible to minimize the specific energy costs per cargo unit, and, accordingly, to increase the energy efficienc of the functioning of the geospace transport system, as well as to reduce the cost of transportation along the Earth – Orbit – Earth route. Nevertheless, it is necessary to provide a system of productive heat removal, since the GPV electrical devices losses are inevitable.

Losses in electrical engineering are largely caused by the remagnetization of ferromagnets in an alternating magnetic field and are the sum of losses due to hysteresis and Foucault eddy currents.

Hysteresis losses are due to irreversible remagnetization processes associated with the rearrangement of the domain structure of the substance due to the lag between the changes in magnetization and in the magnetic field. That is why only part of the energy transferred by the external field during magnetization is returned during the reverse process of demagnetization, and the non-returned part of the magnetic energy turns into heat and is lost. To reduce losses due to hysteresis, soft magnetic materials with a minimum value of coercive force should be used.

Eddy currents arise in a closed conducting loop due to the electromotive force (EMF) of self-induction. To reduce eddy current losses, a material with increased resistance is suitable, and is achieved by assembling a magnetized element from thin plates isolated from one another, as well as by using materials with high resistivity. In this case, the heat release in the belt flywheels should be completely eliminated due to the impossibility of cooling them at cosmic velocities under vacuum.



The amount of heat loss can be determined as follows. It is necessary to put the GPV body with passengers and cargo into a circular orbit with the first cosmic velocity. On the take-off and landing platform, that is, on the surface of the planet, the GPV body has a speed equal to the linear circumferential speed of the equator, – 465 m/s, and in a circular orbit, for example, at an altitude of 400 km, the first cosmic velocity is equal to 7,725 m/s. Each kilogram of mass launched into a specified orbit during the flight must be supplied with kinetic energy of 29.7×10^6 J, or 8.26 kWh. Then the 5 % heat losses will amount 0.413 kWh/kg. In the example under consideration, the specified running weight of the GPV body (with levitation systems and electric drive, with a cooling system, with passengers and cargo, etc.) is 500 kg/m, therefore, the heat release during the time the GPV enters space will reach 206 kWh/m. For the entire GPV body, which weighs 20 mln tons, the total heat release will be 8.26×10^9 kWh. The amount of this energy is enormous, so the heat losses in the GPV electric system must be reduced.

Among the possible technical solutions for heat removal, various options are being considered, but the following two seem to be the most promising. The firs one is cooling with liquid hydrogen. Its advantage is that the GPV needs a capacious source of additional energy, since, unlike a magnetic levitation train, during the flight the GPV has no external sources of electrical energy from where it can be taken and where it can be directed back. This means that after cooling the electrical equipment, hydrogen will be used as an energy source in on-board power plants.

In addition, the heat removal system can be supplemented with water cooling followed by overboard steam discharge. The second option is possible because anyway the GPV will take ballast water into flight for its discharge in the upper layers of the atmosphere, where an active exchange of energy between the systems of the magnetic suspension and the linear electric motor of two belt flywheels is carried out, which is accompanied by the main heat losses in geospace flight. The upper layers of the atmosphere need such emissions, since water vapor will contribute to the restoration of the planet's ozone layer, as envisaged by the EcoSpace programme [5].

To increase the heat capacity, ballast water can be taken on board in the form of supercooled ice (–200 °C). Heating each kilogram of ice to 100 °C with two phase transitions ("ice – liquid" and "liquid – vapor"), followed by evaporation, will consume 0.95 kWh/kg of energy. Then, 217 kg of ice is needed to cool each running metre of the GPV, which is practically equal to its carrying capacity (250 kg/m). Therefore, in its pure form, such a solution is unacceptable. Liquid hydrogen cooled to –257 °C and heated to the same 100 °C will require less, but not much – 146 kg/m. However, taking into account its low density and the large mass of cryogenic, storage and application systems, the hydrogen cooling system will be even more massive than the water one and will exceed the GPV's carrying capacity.

There are two ways out of this situation:

- increase the efficiency of the GPV electric drive up to 98–99 % and reduce the heat release by 2.5–5 times, which will proportionally reduce the mass of the coolant and the cooling system as a whole;

- use atmospheric air as a cooler as the GPV rises up to an altitude of 50 km and even more – up to 100 km. Air density and temperature decrease with altitude. For example, at a distance of 10 km from the ground, the density is 0.414 kg/m3, and at an altitude of 50 km, it decreases to 0.001 kg/m^3 at a temperature range of –75… –20 °C. The outside air-cooling scheme requires such a lifting mode of the GPV, in which the main peripheral speed of its body, up to 7.5 km/s, will be achieved within the atmospheric section for about one hour. This condition will provide an acceptable for passengers acceleration – about 2 m/s^2, i.e., the level of modern airbuses take-off acceleration. That is why the vertical rising speed of the GPV should be kept low – up to 100 km/h. As the linear (circumferential) speed increases, the geospace aircraft will begin to rise into less dense layers of the atmosphere, which will reduce aerodynamic drag at hypersonic speeds. In addition, the GPV body has no frontal resistance, and its side surface, made accordingly, will become a linear radiator of cooling systems. If necessary, rarefi d atmospheric air with the help of special hyperspeed intakes can be supplied to the GPV for use in cooling systems.

There is one more feature of heat release during the launch of a giant aircraft into orbit and the functioning of its flywheel propulsion system. The volume of released thermal energy is directly related to the loss of kinetic energy and, accordingly, the momentum and angular momentum of the GPV ring elements, covering the planet in the equatorial plane. In this case, if the total kinetic energy of all linear elements of the GPV is equal to the kinetic energy of a body with the same mass moving with the first cosmic velocity, then the GPV will be at stable equilibrium state at a specified circular orbit. If the total energy decreases, then the GPV will begin to decrease, and possibly could fall back to the planet. In the case of its increase, the GPV will begin to rise, up to excessive stretching and destruction.

Consequently, during the rising of the GPV into space and the return to Earth, the standard balance of the specified characteristics of the linear components – the body, magnetic suspension systems and electric drive, as well as both belt flywheels – must be observed. In the light of the above mentioned, all the listed components comprise in fact the common flywheel propulsor of the GPV, since each of them has a variable in time and not equal to zero absolute speed relative to the Earth.

In this case, there are three options for energy losses compensation.

Option 1. The starting excess of kinetic energy, momentum and angular momentum, sufficien to compensate for all flight losses, including taking into account the change in the body mass associated with the operation of cooling systems and discharge (or attachment) of ballast. For example, with an excessively rapid decrease in the total mass of the GPV (this is possible with an intensive discharge of the coolant overboard from the cooling system), the rate of its rise will abnormally increase, which can be compensated by the intake of air from the atmosphere on board and its compression in order to increase the density or by the intake of only condensed moisture, contained in the air.

Option 2. Generation of additional electrical energy on board during the flight. The main requirement for an on-board power plant under such a condition will be to minimize heat generation, since cooling the GPV is already the main problem of its operation. This means that the use of thermal power plants, including those operating on hydrogen, is possible only if their efficienc is much higher than 50 %. The problem is aggravated by the fact that, in addition to hydrogen fuel on board the GPV, in this case, it will be necessary to carry an oxidizer – oxygen. In this case, the required mass of oxygen significantly (eight times) exceeds the mass of hydrogen fuel, although, to compensate for the above energy losses equal to 206 kWh/m, it will be necessary to stock up on board (per metre of its length) with hydrogen – 8.85 kg/m, oxygen – 70.8 kg/m, when the efficienc of the on-board power plant is 70 %. However, if oxygen is taken from the atmosphere during the launch into space, then the GPV's carrying capacity, all other things being equal, will increase by 2.8 mln tons. This provision will signifi antly improve the technical and economic characteristics of the GPV – in particular, to perform the same volume of geospace transportation, equal to 2.8 mln tons, the existing rocket and space industry of the planet needs more than one thousand years. At the same time, exactly the same volume of cargo, and just by increasing the efficienc of one of the GPV systems, will be delivered into space in one flight – in about one hour. It is also advisable to use compact onboard nuclear power plants, since during their operation a lot of fuel is not consumed, and the mass of such power plants will be several tenfold less than thermal ones (taking into account the mass of the fuel and oxidizer).

Option 3. Using the differen e in electrical potentials in the ionosphere along the height of the atmosphere and along the equator. For example, the potential difference between the ionosphere and the Earth's surface is 200–300 kV. The Earth and the ionosphere act as plates for a capacitor charged by thunderclouds. The potential difference leads to the appearance of an electric field of the atmosphere. In this case, the main electrical phenomena – the polarization of clouds and their interaction with the Earth – occur in the troposphere, that is close to the Earth's surface. The gradient of the potential of the planet's electric field along the height of the atmosphere is about 150 V/m near the Earth's surface and decreases exponentially with an increase in altitude to 1 V/m and below (at an altitude of 30 km). In the horizontal direction, there are also potential gradients, in particular between thunderclouds, but they are unstable and difficult to predict. A direct current flows between the Earth and the ionosphere with output power of almost 400 MW. The received power is generated by solar radiation. The electrical energy that is accumulated and stored in the Earth's atmosphere is approximately 150 GJ. Part of the accumulated energy can be taken for the needs of the GPV during the flight through the atmosphere [6].

The equatorial strip of the Earth is in many places intersected by mountain ranges rising for several kilometres above sea level. The highest obstacles on the way of the GPV equatorial take-off and landing overpass are the East African Highlands in Africa (Kilimanjaro. Altitude above sea level – 3,460 m) and the Andes in South America (Chimborazo. Altitude above sea level – 4,691 m) [7].

Consequently, the equatorial take-off and landing overpass and, accordingly, the GPV located thereon in the prelaunch state, must provide a sinusoidal equatorial profi e of the motion of the belt flywh els with large radius of curvature, approximately 1,000–2,000 km, regardless of whether this curve is convex or concave. Otherwise, high centrifugal accelerations will significantly increase the starting load on the magnetic levitation system of the flywheel that moves at a speed of about 10 km/s. When designing the profile of an equatorial take-off and landing overpass, it is imperative to provide transition curves between convex and concave curves with a very smooth change in curvature, as well as with the transition of the radius through the value of infinity (through a straight section) in order to exclude shock loads and resonance phenomena in the GPV linear components.

It is necessary to refine out a variant of the GPV and the equatorial take-off and landing overpass design with the "mooring" mechanism, which will allow to ensure tight control of the GPV movement in the time interval from the moment it is on the lodgment of the equatorial take-off and landing overpass, until the start of the lift-off (or touchdown during landing) by its body of the most rising above part of the equatorial overpass. Upon that, the GPV body, after a certain time, will acquire a perfectly rounded shape, "unmoored" and set off for free fl ght. It is important that the process of the transition of the sinusoidal form of a linear aircraft into a rectilinear one (more precisely, into a circle of large diameter, exceeding the size of the planet) is not accompanied by significant transverse accelerations, longitudinal and transverse dynamic oscillations, especially resonance phenomena.

In conclusion, it should be noted that the GPV (as opposed to the magnetic levitation train) is an aircraft. Moreover, a self-supporting one, bearing on itself, and not on air, like an airplane, or a jet stream thrown into the environment like a rocket. That is why, for the GPV, as for any aircraft, the conditions of the minimum dead weight and the highest reliability of the entire structure, as well as each of its functional systems separately, are considered critical.

8.3 Conclusions and Future Work

All the specific design features of the GPV identified by the authors require the most thorough research and development work (R&D). At the same time, the search for new specific design features and their design and technological study must be carried out on an ongoing basis.

Considering the uniqueness of the developed astroengineering technology and the extra high level of responsibility for the design and technological decisions made, experimental work with the creation of small prototypes of the GPV at the initial stages of R&D is of particular importance. At the same time, the sophistication of the design and the reliability of the functioning of the GPV prototypes must correspond to the level inherent in mass-produced products. For this, it is proposed to implement, in parallel with R&D, an investment project for the production of kinetic energy storage devices with linear flywheels of various diameters. First, it is important to master storage rings with diameters of tens and hundreds of metres, then – kilometres and tens of kilometres, so that, while working out the design and increasing its reliability, gradually increase the operating speeds of rotation of linear flywheels to the values of the first cosmic velocity. At present, the rapidly growing market of kinetic storage devices is represented only by small systems with fl -wheels rotating on an axis, which, due to their low power consumption, can only provide equalization of mains voltage drops, as well as short-term backup power supply. Kinetic drives with belt flywheels of the GPV type will make it possible to create kinetic drives of high energies, which means they will be able to equalize daily flu -tuations in energy consumption and guarantee the growth of net capacities of the operating power systems of certain regions and even countries.

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9

Use of Hydrogen in Outer Space: Past, Present, and Future

9.1 Introduction

The General Planetary Vehicle (GPV), created by engineer A. Unitsky, is a reusable geocosmic transportation and infrastructure complex for the non-rocket space exploration with the aim of creation and functioning of the near-Earth space industry. The first space launch of the GPV will enable establishment of a basic infrastructure, energy, and information complex as the foundation for creation of Industrial Space Necklace “Orbit” (ISN “Orbit”) [1].

The GPV delivers people and cargo loads from the Earth to the modules of ISN “Orbit”. Space vehicles can further be launched from ISN “Orbit” to the further placed object in the Solar System, for example, to the Moon or Mars. Transportation of the cargo goods to the orbit is the most expensive stage of the space development. The GPV resolves this problem with minimal energy expenditures. One run of the GPV can replace approximately one million launches of American Space Shuttle heavy missiles [1].

When a mathematical GPV model was created [2], the required parameters of the GPV operation were considered with the necessary global scale, including: the speed functions; forces applied to the GPV during take-off process; electrical energy consumption to speed-up the rotor of the GPV in the terrestrial conditions. Various methods and options were evaluated to create smooth and steady fligh and fix tion at a given orbit. The design option with sequential conversion of kinetic energy of the first linear reaction flywheel to the energy of the second flywhee of the same size was identified as the most optimal architecture, considering energy efficiency and engineering feasibili .

The energy produced as a result of recuperative braking of the first belt fl -wheel will be directed at speeding up of the second belt fly heel in the reverse direction. However, this energy is not sufficien for stabilization of the flight process due to the energy losses in the recuperation system. The lost energy may additionally be obtained from the process of hydrogen burning on board of the GPV, being the most energy-intensive carrier in the fuel cells. In the process of conversion of kinetic energy of the first flywheel intro electrical energy by the linear motor-generator and further reversing the energy from electrical state into mechanical energy of the second fl wheel, the loss will reach 1.148 GJ for each metre of the GPV's length [2]. The heating value of hydrogen is low and approximately equal to 140 MJ/kg. If efficiency of a hydrogen fuel cell is taken within the order of 50 %, 16.4 kg of hydrogen will have to be burned for every metre of the GPV's length that leads to the consumption of 131.2 kg of oxygen. These masses can be included into the dead weight, which will be loaded to the freight compartments of the GPV.

In order to supply the GPV with the required amount of hydrogen, the problems with its generation, long-term storage and further utilisation have to be resolved.

Various hydrogen storage systems are reviewed in the paper, including advanced ones. The paper compares them with respect to their possible use in the GPV and ISN "Orbit". Research activities reviewed issues for on-board usage of hydrogen systems, refuelling processes, and hydrogen production within outer space conditions. Furthermore, approach included study of the possible transportation of the excessive hydrogen to the Earth to get additional clean energy resource.

9.2 Hydrogen Storage on the GPV and in ISN "Orbit" Modules

Hydrogen storage systems have some peculiarities, because under normal conditions, hydrogen has very low density (0.0898 kg/m3) and, to provide necessary amount of power, it occupies relatively large volume. In order to increase density and, consequently, reduce the useful volume, hydrogen is turned in the liquid state by decreasing hydrogen temperature to cryogenic values, increase in hydrogen pressure, and use of hydrides, many of which are chemically active in air or in the presence of water. Storage reliability and safety are the key requirements for any storage system.

The following storage concepts are seen as the most perspective solutions for the GPV application: high-pressure tanks for gaseous form; liquid hydrogen storage systems; hydrides-based systems; microspheres; cryogenic vessels; and capillary structures.

Properties of hydrogen storage systems are determined by the following parameters: volumetric density (kg/m3) – ration between hydrogen mass and its volume; gravimetric density (mass % H_2) – ratio of hydrogen mass to storage system mass; working pressure (MPa); operating temperature (°C); storage safety.

A. Storage of Pressurized Gaseous Hydrogen

Technology of pressurized hydrogen storage has been used for a long time. The key advantage of this solution is absence of power consumption during gas release procedure.

Under atmospheric pressure and normal room temperature, 1 kg of hydrogen in the unbound state occupies volume of 11.12 m^3. To reduce occupied volume, hydrogen should be compressed to the higher pressure level. According to the ideal gas state equation (1), the higher gas pressure leads to the decreased volume:

$$PV = nRT, \tag{1}$$

where P – hydrogen pressure;
V – hydrogen volume;
n – hydrogen quantity (moles);
T – temperature;
R – universal gas constant.

Gaseous hydrogen storage is similar to the natural gas storage. In the context of hydrogen, the special requirements are applied to the materials of the canisters. Materials should not become brittle in the presence of hydrogen. Considering standard steel canister having the volume of 40 l with hydrogen under pressure of 15 MPa, it can be seen, that each one contains 540 g of hydrogen. The package density of this solution is equal to 13.31 kg/m3 taking into account standard weight of the canister. The use of special storage bottles makes it possible to improve this parameter. Once the pressure is increased to 40 MPa, the mass of stored hydrogen growths to 1,440 g. One of the advances solutions includes usage of titanium canisters as a storage system to achieve higher pressure levels [3].

The best features have been demonstrated by the composite bottles, which are made of the internal sealing layer based on a dense polymer with carbon fiber winding, which is covered by a layer of epoxy resin impregnated by glass-cloth. The latest developed canisters, made of reinforced carbon fib rs, demonstrated maximum applied pressure of up to 70 MPa, which gives density of 62.1 kg/m3. Furthermore, such bottles have a lifetime of up to 15 years.

B. Liquid Hydrogen Storage

The key advantage of liquid hydrogen storage system is its larger volumetric density reaching values of 70.811 kg/m3. However, specific requirements are applied to the materials in the cryogenic resistance (–253 °C), as well as effective heat insulation and continuous cooling. The liquid hydrogen has to be filled in the prior cooled down canisters. Cooling process has high hydrogen consumption. Evaporation losses pose another problem regarding the storage systems. Evaporated hydrogen should be used in fuel cells or collected in metal hydride.

Hydrogen liquefaction is an energy-consuming process. Bottles for liquid hydrogen storage are more complicated in comparison with storage tanks for other cryogenic liquids. In addition, the system shall be equipped with the safety pressure valves. Also bottles for liquid hydrogen are equipped with the devices for liquid hydrogen charging and discharging. Strict requirements are imposed on the thermal insulation of the bottles. It is impossible to entirely avoid evaporation losses, whatever the efficiency of the thermal insulation

Liquid hydrogen storage within the GPV and in ISN "Orbit" is efficien due to the low temperature conditions and structures, which are located in the shadowed side of the systems.

C. Storage of Hydrogen in the Form of Hydrides

Hydrides are compounds of hydrogen with the metals or intermetallides (intermetallic compounds). Hydrogen storage in the form of hydrides has several advantages, such as no need to support high pressure or low temperature conditions, that should be supported during the complicated processes of canisters manufacturing.

Use of hydride-based storage places the following requirements to the operating state: dissociation temperature close to 20 °C, dissociation pressure, heat transfer during formation of hydrides, absorption and desorption processes, cycled load during charging and discharging, cost, filling infrastructure availability, operating safety. Existing researches identify the following types of hydride to be used [4]:

- simple (binary) metal hydrides, for example, magnesium hydride MgH_2. The research of these elements started more than 40 years ago. As benefits, such solutions have high volumetric (109 kg H_2/m^3) and mass (7.6 mass % H_2) density;
- hydrides of intermetallic compounds, for example, Ti_2Ni, $LaNi_5$, $CeNi_4Zr$. Intermetallic compounds are chemical compounds of two or more metals (Figure 1);
- complex hydrides of light metals, including aluminum hydrides ($LiAlH_4$), boron hydrides ($Mg(BH_4)_2$), hydrides based on metal amides (non-organic compounds containing NH_2^- ions, which are also ammonia derivatives, where a hydrogen atom is substituted with a metal atom, for example, $LiNH_2$).

Figure 2 shows key performance indicators of hydrogen storage systems when different hydrides are in use. Volumetric and gravimetric densities are defined as part of the evaluation. Performance indicators for liquid and pressurized gaseous hydrogen and Li-Ion battery systems are given for comparison.

Hydrides solutions perform better values of gravimetric and volumetric densities among the alternatives (Figure 2). For example, H_2 content in KBH_4 is equal to 83 kg/m3 and 7.4 mass % H_2; in $NaBH_4$ – 112 kg/m3 and 10.5 mass % H_2; in NH_3BH_3 – 145 kg/m3 and 19.5 mass % H_2.

Higher gravimetric and volumetric densities enable to decrease volume and mass of storage systems while keeping the same energy parameters. Hydride-based systems need no additional requirements regarding the safety perspectives, in comparison with pressured or liquid hydrogen storage systems. Furthermore, it has no losses, associated with liquefaction or compression of the hydrogen.

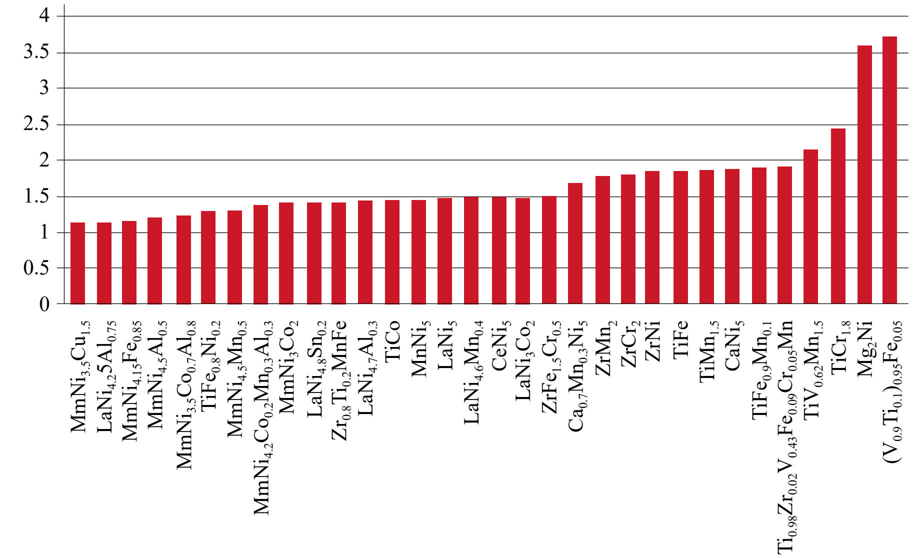


Figure 1 – Hydrogen capacity of intermetallic hydrides (mass % H_2) [4]

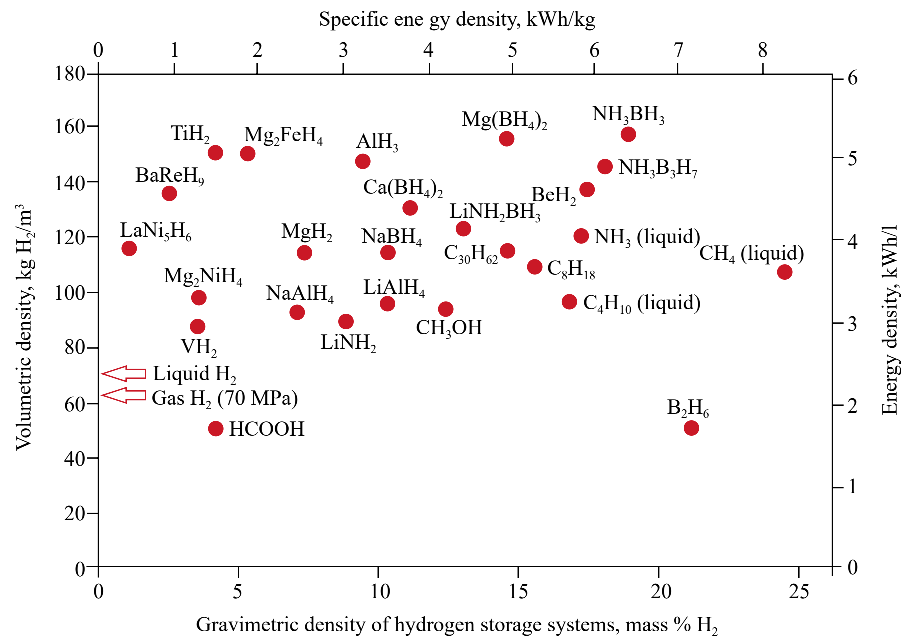


Figure 2 – Volumetric and gravimetric density of hydrogen storage systems [4]

In terms of safety, use of hydrides possesses less danger. Failure of a high-pressure canister is signifi antly more dangerous than failure of a bottle with the hydrides.

The absorption properties of the intermetallides are in Table 1.

Table 1 – Properties of hydrogen absorption/desorption by some intermetallides

Chemicals	T_{abs}/T_{des}, °C	P_{abs}/P_{des}, MPa	$t_{abs}/t_{des.}$, min	Stability, cycles	Maximum mass of H_2, %
$La_{0.9}Ce_{0.05}Nd$	100	0.5–1/0.024	6.6/6.6	20	0.95
$Zr(Cr_{0.8}Mo)_2$	120	3/0.1	6.6/6.6	40	0.99
$Ml_{0.85}Ca_{0.15}Ni_5$	25	3/1	60/60	100	1.1
$LaNi_{4.8}Sn_{0.2}$	80	4/0.3–0.4	60/60	100	1.16
$Ti_{0.9}Zr_{0.15}Mn_{1.6}$	25	1/0.1	60/60	100	1.3
$MmNi_{4.6}Al_{0.4}$	25	3/2.5	4/5	11	1.3
$Ti_{1.1}CrMn$	23	3.3/0.1	1/5	1,000	1.8
$Ti_{43.5}V_{49}Fe_{7.5}$	20/300	10/1	20/25	50	3.9

Processes of spontaneous hydrolysis/oxidation in air are typical for most hydrides, as well as the most active compounds are able to self-ignite. Formation of toxic compounds is a negative factor in operation with the hydrides. For example, this issue is applied to the boron hydride based solutions. Such hydrides are not suggested for usage in storage systems.

Hydrogen can be extracted from hydrides by one of the following ways: through hydrolysis, when hydride is getting separated with parallel formation of new compounds; and dissociation, that means separation of molecular complexes into several smaller molecular structures.

For the hydrogen output evaluation, hydrolysis process provides more benefits with applying only one limitation – this process is not reversible [5].

D. Hydrogen Storage in Encapsulated State in Microspheres

The hydrogen storage in glass microspheres was proposed recently. Microspheres have diameters of 5–200 µm. The walls of these spheres contain numerous pores with diameters varying from 10 to 1,000 angstroms and their thickness is of 0.5–5 µm. Microspheres are fi led with hydrogen under high pressure and at the temperature of 200–400 °C. At this state, hydrogen diffuses through walls of microspheres, and after cooling, hydrogen is kept in microspheres under the pressure. When microspheres are heated up to 200–400 °C, hydrogen can be removed from them.

Hygrometric density of hydrogen in the microspheres reaches 11–12 mass % H_2. Theoretically possible pressure within the microspheres can reach 85–100 MPa. Diffusion losses of hydrogen through the walls are equal to 0.5 % per day. Stronger microspheres are being developed with the use of metal coating of external diameter ranging between 50–1,000 µm and wall thickness of 0.6–7 µm. The metal coating will significantly reduce diffusion losses by approximately ten times

Hydrogen storage systems using microspheres are now at the initial stage of development. Value of 2.2 mass % H_2 was reached during initial experiments with the pressure of up to 10 MPa in order to avoid failures of the microspheres.

This method is potentially safe as hydrogen can be kept at the room temperature for relatively long period of time. Its disadvantages include required heating of microspheres during the filling and extraction processes with high energy consumption to achieve the necessary temperatures.

E. Hydrogen Storage in Capillary Structures

Nanotubes are considered to be a prospective hydrogen storage solution. This solution is capable to absorb hydrogen providing high capacity (Table 2). Hydrogen is being absorbed by the carbon structures and placed between carbon nanotubes. Single-layer carbon nanotubes being packed in parallel and forming a triangular lattice, have high potential as a hydrogen storage solution. Distance between such tubes is equal to 0.337 nm. This package of nanotubes forms numerous cavities in the carbon structure and that increases absorption properties of the material. The size of formed cavities is comparable to the size of a hydrogen molecules.

To intensify the system absorption of hydrogen, high pressure is applied.

Heating of the obtained carbon structure leads to the hydrogen desorption. One of the tasks is increasing of hydrogen-carbon relation within the nanotubes [4].

Table 2 – Specifications of hydrogen storage systems with the use of carbon nanotubes [6

Hydrogen pressure, MPa	Temperature, °C	Gravimetric density, mass % H_2
0.04	–140	5–10
0.1	26	6.5–7
5–10	–196… +27	3.5
7.18	–193	8.25
10–12	27	4.2

F. Comparison of Hydrogen Storage Systems

Parameters of various hydrogen storage systems are shown in Table 3.

Analysis of the existing systems, discussed above, shows that the currently feasible methods have their own advantages and disadvantages. Package density is insufficien in the compressed forms, but such solutions are cheaper in comparison with alternative ones, while charge-discharge processes are performed without specific equipment. Liquid hydrogen storage system has higher packaging density, but the cost and complexity of the storage equipment and charging/discharging and evaporating devices are rather high. Hydride-based solutions have significantly higher safety, but with low recharging possibilities. The optimal method of hydrogen storage, which combines high packaging density and safety and supports multiple recharging cycles has not been developed yet. Currently available solutions for hydrogen storage demonstrate that the best ones for the GPV can be found among liquid hydrogen storage solutions.

Table 3 – Parameters of hydrogen storage systems

Storage method	Storage pressure, MPa	Storage temperature, °C	Volumetric density, kg/м^3	Gravimetric density, mass % H_2	Technology availability
Gaseous	70	0	62.1	7–9	Available
Liquid	0.1	–253	70.81	7–12	Available
Hydride $LiBH_4 + SiO_2$	5	20	145	19.5	Under development
Microspheres	10.3	20	7–10	11–12	Under development
Capillaries	0.2	20	8–21	5	Under development

9.3 Hydrogen Formation in ISN "Orbit" Modules

A. Water Electrolysis

Installation of solar panels on ISN "Orbit" will provide generation of required electric power to enable electrolysis process. Usage of water, including seawater, on board of the GPV with its subsequent electrolysis on ISN "Orbit" will support the astroengineering transportation system needs in water and hydrogen resources.

Voltage exceeding 1.23 V is sufficien for water decomposition process. Clean water hardly conducts electricity, therefore potassium hydroxide (KOH) or sodium hydroxide (NaOH) have to be added as electrolyte.

Water generator effectiveness can be calculated as ratio of the energy required to generate 1 kg of hydrogen, to the hydrogen calorific value, which is 142 MJ/kg. The lower this ratio, the higher generator efficiency. An electrolytic cell having 100 % efficiency will consume 39.4 kWh (142 MJ/kg) to produce 1 kg of hydrogen.

Efficienc of a commonly used alkaline electrolytic cell is about 70 %. Electrolytic cells with a proton exchange membrane perform higher efficien , but are more expensive as platinum-based catalysts are used. For large hydrogen production volumes, efficiency of these cells is 80–86

Pros and cons of photovoltaic (PV) panels usage in outer space should also be evaluated, as they are significant part of the system. Advantages include permanent presence of the Sun throughout the day; higher density of electromagnetic flow absence of atmospheric interferences; weather and shadow independence.

The key weak points are accelerated degradation of panels (under the influenc of strong radiation emission); necessity for multiple duplication of electric circuits; increased demand of mechanical protection (serious damages to panels can be caused even by micrometeorites).

Electrolysis of seawater has some additional aspects. Chlorine atoms (NaCl) cause anode corrosion during the electrolysis. Seawater can be purified, but this process will require extra energy.

A team from the Stanford University has developed a corrosion resistant electrode, even during operation in seawater [7]. Such resistance is achieved due to special material composition. Scientists created a spongy layer on the surface of nickel, later it was treated with sulfur to get a nickel sulfide layer, and then a cover made of nickel and iron alloy was applied. The obtained negatively charged sulfate and carbonate molecules in the catalyst layer repel negatively charges chlorine atoms that provides operation of the electrode without corrosion process.

The tests showed that such structure with microscopic pores sustains impact of aggressive chlorine ions throughout thousands of hours, and it is capable of getting hydrogen by means of electrolysis of salty water with the same efficiency, as the industrial units, designed to work with the fresh water.

B. Photocatalytic Water Cleavage

Photocatalytic water-methanol solution cleavage with the use of N-La/TiO_2 semiconductor photocatalysts is one of the prospective methods of hydrogen generation from water [3]. The current development includes creation of photocatalysts sensitive to visible light on both molecular and nanometric levels.

The method may be of special interest for implementation on ISN "Orbit". Sun light intensity on the orbit is higher than in the terrestrial conditions, as significant part of the light is absorbed or reflected in the Earth atmosphere.

Practically all existing photocatalysts cannot work with untreated seawater as they quickly become unable to perform hydrogen formation because of high concentration of salts and presence of materials of biological origin in the water.

C. Liquid Hydrogen Formation

Gaseous hydrogen occupies a large volume even in the highly compressed state. Increased hydrogen density can be achieved by its cooling down to –253 °C.

In the conditions of outer space, it is possible to use passive methods without any power units. Cold constructions within the shaded areas of ISN "Orbit" can be used for hydrogen cooling until the liquid state. Additionally, shading of various elements of the cryogenic unit with the use of aluminum sheets can be organised not only from the insolated side, but also from the Earth side and from each other side (it is known that temperature goes down to –163 °C on the surface of the cosmic objects located in the shade of the Earth).

Further cooling and liquid hydrogen formation can be performed in the course of multi-stage cooling process of simple throttling combined with pre-cooling stage with the use of liquid nitrogen, adsorption-based low temperature purificatio of compressed gas and two-stage ortho-para conversion.

D. Triple Point Hydrogen

One litre of liquid hydrogen is only 0.07 kg, with its volumetric density being equal to 70.811 kg/m^3 at –253 °C. In order to get higher volumetric density, liquid hydrogen should be converted to the state adjacent to its triple point. The triple point is an intersection of stable phase curves on the flat diagram of the substance state, conforming to stable balance of three phases (solid, liquid, and gaseous physical form). Conditions of the triple point for the hydrogen are as follows: temperature of –259.34 °C and pressure of 7,042 Pa (0.0695 atm). At temperatures slightly higher than the triple point temperature mixture of solid and liquid hydrogen can be obtained. Such a mixture is forming a suspension, which is called slush hydrogen. Hydrogen in this state has the highest volumetric density which is 15 % higher than the density of liquid hydrogen and it is equal to 81.6 kg/m^3.

9.4 Use of Hydrogen and Oxygen on the Board of the GPV and ISN “Orbit”

Hydrogen can be used as energy source on the board of the GPV during ascending to the orbit and for stabilization of the GPV and ISN “Orbit” sections.

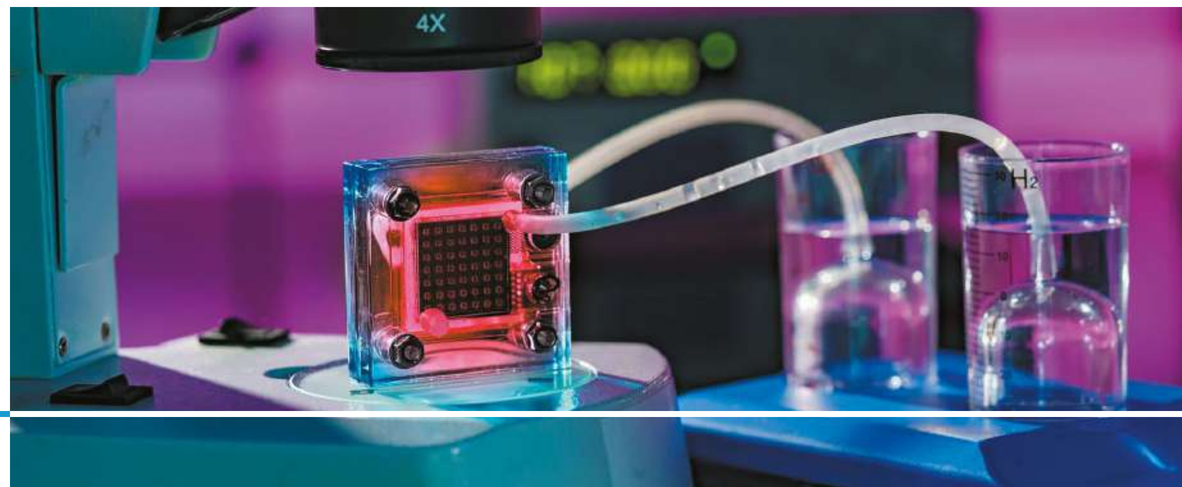
Prior the GPV take-off special cryogenic tanks are being filled with liquid oxygen and hydrogen. By passing through the cooling system of the engines magnetic systems oxygen and hydrogen are warmed up and convert into the gaseous form. Gaseous hydrogen and oxygen are delivered to the low temperature fuelling elements. Electric energy is generated in the fuel cells and fed to the linear motors for the necessary acceleration. One kilogram of hydrogen allows to generate about 71 MJ (19.7 kWh) of energy with the efficienc of the fuel cells of about 50 %. The water is formed in the fuel cells during this generation process.

After reaching the near-Earth orbit water can be used for the needs of ISN “Orbit” or separated into hydrogen and oxygen through electrolyte or photocatalytic methods. Oxygen can be used in life support systems of the GPV and ISN “Orbit”, especially in the habitable sections. Oxygen and hydrogen obtained from electrolysis, are liquefied and delivered back to the cryogenic tanks.

Later on, liquid hydrogen and oxygen can be used for energy generation in the fuel cells during the GPV landing processes.

Liquid hydrogen and oxygen having cryogenic temperatures can be used as a highly efficient cooling agent in the G and ISN “Orbit” systems.

Liquid hydrogen and oxygen obtained on the board of ISN “Orbit” may be transported to the Earth by the GPV for their further use in sustainable energy generation systems.



9.5 Use of Hydrogen for Refuelling of Space Transport

Overcoming gravitation forces of the cosmic items and necessary acceleration of the vehicles to the cosmic velocities requires large amount of energy, which also associated with the relevant consumption of fuel. A space vehicle should have on its board the margin of the working fluids. Release of these substances creates changes in the vehicular impulse.

Two-component fuel – liquid hydrogen and oxygen – will provide necessary energy and margin of the working fluids for the GPV. Both components can be generated in the process of water electrolysis by using solar energy. Units and materials are placed to the near-Earth orbit by the GPV to support the ISN “Orbit” assembly. Further production can be accomplished on the board of ISN “Orbit”, which should be equipped with the orbital fuelling complexes for refuelling the GPV with hydrogen and oxygen.

Two-component fuel (hydrogen-oxygen) weighs three times less than the kerosene-oxygen mixture, that is a signifi ant aspect of the GPV mass reduction. The hydrogen-oxygen mixture, used for launching from the near-Earth orbit, is the most effective pair in comparison with other fuel – oxid zer solutions.

9.6 Conclusions and Future Work

The research covered various systems of hydrogen storage, including prospective ones, the issues of hydrogen usage on the board of the GPV and ISN “Orbit”.

At present, liquid hydrogen storage at cryogenic temperatures is the most acceptable solution for the considered conditions, as it is associated with possible provision of low temperatures by using cold constructions on the shade sides of the objects in outer space.

The use of hydrogen will resolve problems of energy losses compensation in the GPV in the process of reaching the orbit and during its return to Earth. To achieve higher efficien , more effective methods of liquid hydrogen and oxygen storage should be developed, as in the studied examples their total mass, along with the storage and consumption systems exceeds the carrying capacity of the GPV – 250 kg for each metre of the GPV’s length. Vehicle with such a large weight will be unable to take-off. An effective method of the GPV mass reduction includes reduction of the energy consumption, which will lead to reducing of the hydrogen – oxygen pair mass. This can be achieved by efficienc improvement for the linear electric engines of fl wheels through the superconductivity effects, as well as by optimising the modes of the GPV route to the orbit in order to increase its total efficien , for example, up to 99 %.

Liquid hydrogen and oxygen, being stored at cryogenic temperatures, may additionally be used as an efficient cooling agent in the systems of the GPV and in the ISN “Orbit” manufacturing sites.

Hydrogen may also be used as the working fluid during the trajectory correction for both the GPV and ISN “Orbit”. Oxygen and hydrogen can be generated on ISN “Orbit” using the process of electrolysis. Solar panels will be used to provide energy for this process. Oxygen, obtained in ISN “Orbit”, can be used to support habitable cosmic objects, and hydrogen can be transported to the Earth for further energy generation.

In order to resolve the problems of hydrogen generation and using at the space objects, subsequently, it is necessary to evaluate needs of the GPV, ISN “Orbit”, and other cosmic vehicles in hydrogen and oxygen, as well as eff ctiveness of electrolysis cells employment should be determined which operation depends on the energy from solar batteries installed on ISN “Orbit”.

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10

Methods to Convert Solar Radiation Energy into Electricity for Needs of Industrial Space Necklace "Orbit"

The main types of energy that will be required for the life support of Industrial Space Necklace (ISN "Orbit") [1] will be electrical, mechanical, thermal, and luminous ones. Solar radiation is the only primary source with the possibility to transform its energy into other usable forms directly on orbit.

Direct or concentrated solar radiation can be converted into thermal energy of heated bodies, and then, through direct or machine transformation, into electrical energy. The temperatures of the heated bodies depend on the density of the incident radiation and the arrangement of heat transfer processes, including reverse thermal radiation from the surface (Figure 1).

Solar energy can be directly converted into electrical energy by means of photovoltaic systems. The maximum flux density of solar radiation outside the Earth's atmosphere is 1,367 W/m^2, and on Earth it is about 1,000 W/m^2 (at the surface perpendicular to the radiation). However, this value is usually much lower due to adverse weather conditions (cloudiness, fog, smog) or economic inappropriateness of building systems for tracking the sun. Accordingly, the effectiveness of any solar-based generation solutions will be higher in the outer space.

Currently, the most widely used method for generating electricity in space is the direct conversion of solar energy into electric power based on the photoelectric effect. A photovoltaic (PV) system is set of several combined semiconductor devices that convert solar energy into direct electric current [2]. The photovoltaic cell

consists of two semiconductor wafers made of silicon. To give them conductive properties, boron (*n*-area) is added to one of them, and phosphorus (*p*-area) is injected into the other (Figure 2).

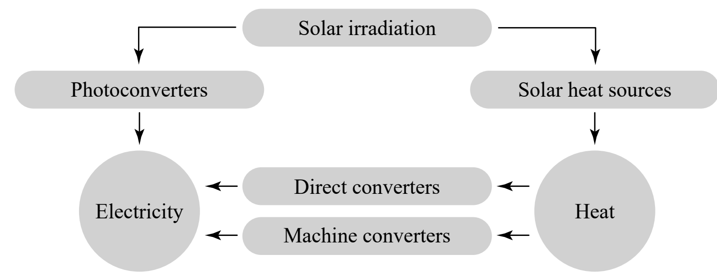


Figure 1 – Diagram of ways to convert solar energy into electricity

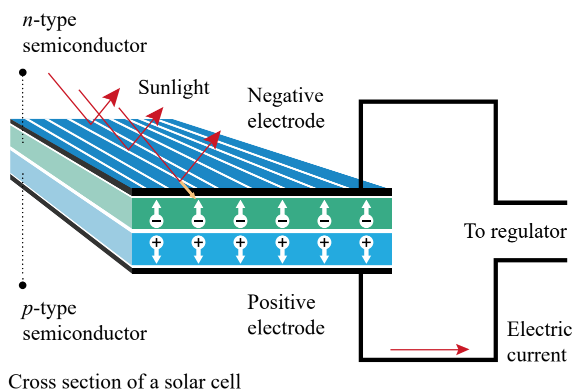


Figure 2 – Schematic diagram of solar battery

Improving the efficienc of PV is possible in the following ways: the use of new materials, use of solar concentrators (for example, Fresnel lenses) or solar tracking systems application. Concentrators increase the radiation flux density, therefore, reduce the required area of PV cells with equivalent output power, thereby reducing the cost of a solar station due to the reduced number of required cells.

Objects in near-Earth orbit revolve around the Earth within 1.5 hours and they are placed periodically in the shade. Therefore, the use of batteries is required to maintain continuous power supply. Each of the solar panel (105 m^2) at the International Space Station (ISS) has six nickel-hydrogen batteries. The service life of such batteries is approximately seven years [3].

Nowadays, solar cells made of gallium-arsenide heterostructures (GaAs) are demonstrating promising results in terms of specific power. However, they have a higher specific weight and a higher specific cost in comparison with silicon-based (Si) panels.

Furthermore, GaAs based panels have not been tested explicitly within the "low" orbits (less than 500 km) in the presence of a noticeable dust "atmosphere" around the station and under conditions of constant thermal cycling (16 cycles per day). The temperature of the solar battery in the shadow of the Earth drops to –45... –60 °C. Moreover, when entering the Earth's shadow, the battery temperature drops in 2–3 min by 70–90 °C. After leaving the shade with frontal lighting, the temperature quickly enough (in 1.5–2 min) rises to 65–75 °C; when illuminated from the back, the PV temperature increases at slower pace – in 10–15 min up to 40–45 °C [3]. Based on the given operation conditions, silicon-based photoelectric panels have been used on the ISS and transport ships so far.

Power plants with thermodynamic methods of energy conversion are much more complex in their structure. Thermal power plant consists of three main systems: a source of heat, transformation of thermal energy into electricity and heat removal.

Arrangement of heat removal is an important issue in the conditions of outer space, because traditional methods, typically utilised for terrestrial conditions, cannot be used. Radiation is the only feasible mechanism for heat removal in space. Installations designed to remove heat are called radiant coolers.

The defining equation for radiative heat transfer from the body is $Q_r = \varepsilon A \sigma T^4$, where ε – emissivity (degree of blackness) of the body surface;

A – heat transfer area;

σ – Stefan – Boltzmann constant;

T – absolute body temperature.

As can be seen from the above equation, the power of thermal radiation of a refrigerator is directly proportional to the area of the radiator, and with increasing radiation temperature, the amount of heat removed increases to the fourth power. Therefore, to reduce the size and weight of the radiant cooler, it is necessary to raise the temperature of heat removal. On the other hand, as the temperature of heat removal increases, the efficienc factor of the station cycle decreases, which is determined by the expression:

$$\eta = C(T_{max} - T_{min})/T_{max}.$$

T_{max} temperature should be maximum, however, it is limited by the properties of construction materials. T_{min} temperature is the minimum cycle temperature and should be as low as possible.

Thus, during design process for the space power installations, it is necessary to solve the problem of choosing the minimum temperature of the cycle. In this respect, the mass of the radiant cooler, which makes up to 50–60 % of the mass of the system, should be taken into account. The dimensions of the radiator can be reduced by increasing the maximum temperature of the cycle, which will lead to a drop in the efficienc of the converter. Increasing the maximum temperature of the cycle is possible with the use of rare and expensive materials.

The second group of methods for obtaining electrical energy from solar radiation is based on the processes of an indirect transformation with an intermediate

generation of thermal energy. According to the type of converter of thermal energy into electrical one, all solar power plants can be divided into two groups: systems with direct "machineless" conversion of thermal energy into electrical energy [4, 5] and systems with an intermediate change of thermal energy into mechanical energy [6, 7] (using machine converters). Thermoelectric phenomena include a group of physical phenomena caused by the existence of an interconnection between thermal and electrical processes in electrical conductors [8].

In a closed circuit made of diff rent materials, a thermoelectromotive force (TEMF) arises if the contact points (junctions) are maintained at different temperatures (the Seebeck effect [9]. TEMF depends only on the temperature diffe - ence between hot and cold junctions and the nature of the materials that make up the thermoelement. If there is a temperature difference at the ends of the conductor, a stream of electrons from the hot end to the cold end arises. A negative charge is accumulated at the cold end. The resulting potential difference creates a countercurrent of electrons equal to the primary flow caused by the difference in thermal velocities. Difference in potentials' drop in to conductors form a thermoelement that causes the occurrence of TEMF.

The first solar thermoelectric generator for space purposes was created in the USA. Thermoelectric elements (TEEL) with a combined volume of 2.5 mm^3, placed between two plates of metal foil, were used in the design. About 3,000 units were included into 1 m^2 (Figure 3). In outer space, the plate facing the Sun heats up to 300 °C, and the cold side has a temperature of about 70 °C. Each element in this structure produces 10 mW with an efficienc of about 2 %. 1 m^2 of the thermoelectric panel of the model weighs 10 kg and produces approximately 30–40 W/m^2 of electricity. A solar generator for a spacecraft with a surface of 30 cm^2 with 12 rows of TEEL (12 TEEL in each row) was characterised by the generation of 2 W of electricity in space, as was analysed in [10].

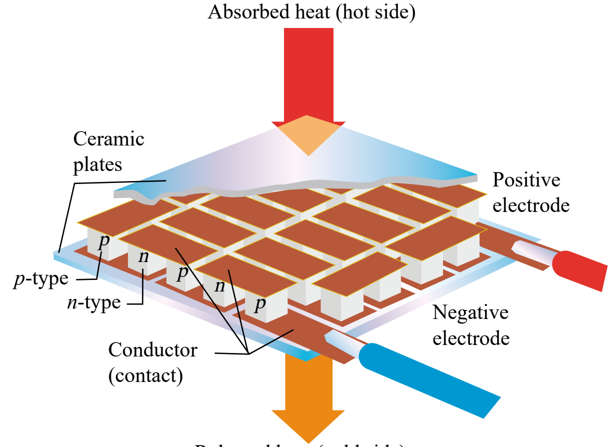


Figure 3 – Thermoelectric converter design

To increase the temperature gradient between hot and cold junctions, it is possible to use solar energy concentrators, which allow increasing the temperature of the hot junction to 1,000 °C. Correspondingly, the efficienc increases, which grows in proportion to the temperature difference between hot and cold junctions and the absolute temperature of the hot junction.

Extensive tests of generator modules were carried out in terrestrial conditions. According to the results, dependences of power, voltage and current on the temperature difference between cold and hot junctions were defined (Fi re 4) [11].

A thermoelectric module with a concentrator (Figure 5), is a thermopile placed at the focus of a spheroidal or cylindrical mirror.

Three main types of heat conversion machines, which can be used in space solar stations, are gas piston, gas turbine, and steam turbine, functioning using Stirling, Braytonn and Rankine cycles.

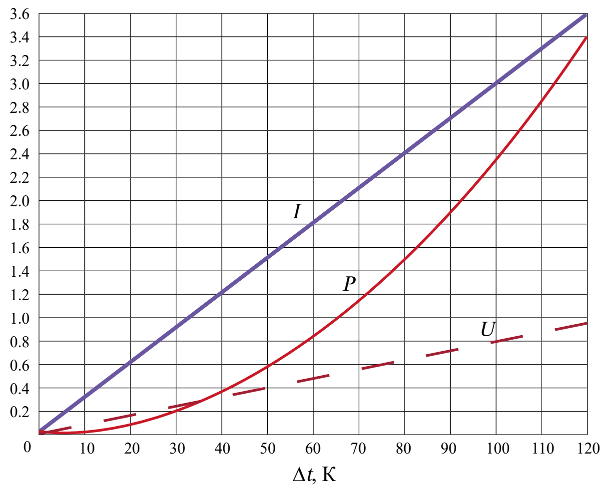


Figure 4 – Dependency graph of current *I* (A), voltage *U* (V) and power *P* (W) on the temperature difference between the hot and cold sides of the generator module

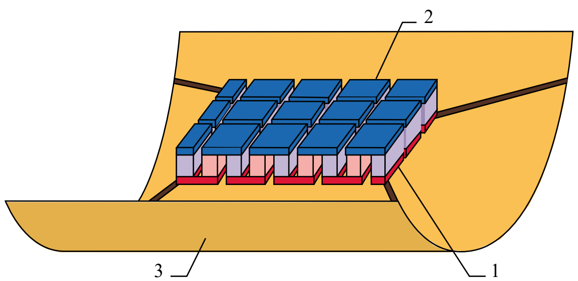


Figure 5 – Thermoelectric module on a cylindrical concentrator: 1 – hot junctions; 2 – cold junctions; 3 – concentrator

In solar thermal power installations with machine converters, thermal energy is supplied to the working medium of the converter, which is in a liquid or gaseous state. Then it is converted into mechanical energy in a steam or gas turbine converter or in a piston machine. Created mechanical energy is converted into electrical energy using electric generators.

Stirling engines are machines with reciprocating motion (other schemes of Stirling engines with rotational motion also exist).

The American company General Motors developed a 3 kW space power plant. Helium was used as the working medium for the Stirling engine at an average pressure of 10.3 MPa, and heating was carried out by means of solar radiation, which was concentrated using a large Fresnel lens. A distinctive feature of this engine is as follows: this is the first of the Stirling engines, which uses an intermediate liquid metal coolant (NaK) at a temperature of 677 °C to heat the working fluid The calculated effi ency of the engine is 30.5 %. During the first tests, a power of 2,565 W was achieved with an efficiency of   % [12].

In the cycles of gas turbines for space purposes, inert gases and their mixtures are used as working fluids. Their positive side is the absence of phase transformations and the almost complete absence of erosive and corrosive effects of the working fluid on the mechanical elements of the system

The Brayton cycle has a relatively low efficien , large costs of turbine power to drive the compressor and significant pressure losses of the working fluid within the elements of the heat exchanging equipment of the converter. As a result, the characteristic values of the utilisation coefficien for gas turbine converters do not exceed 0.25, and to obtain high efficienc of the converter, it is necessary to increase the temperature difference in the cycle, mainly by increasing the gas temperature in front of the turbine, i.e., in the radiation detector.

The isothermal nature of heat supply and removal processes in the steam turbine converters signifi antly raises the thermal efficiency. In addition, unlike gas turbines, there are lower costs to drive the pump, which in the combination with other measures allows to obtain rather high values of the utilisation factor (~ 0.5) and, consequently, the overall efficiency (20–25 %), which raises with the growth of the system's capacity. These factors determine the key advantages of steam-turbine converters over converters operating according to the cycles of Brayton and Stirling with respect to the requirements for thermal converters of solar energy, as the principle schemes (Figure 6).

The efficiency of steam turbine converters largely depends on the properties of the working fl id, which can be water, liquid metals or organic compounds. The developers of thermal solar space station projects have concluded that the most suitable working bodies for steam turbine converters are liquid metals [13]. Potassium and cesium are among the most optimal, but potassium is preferred, because of its greater availability in the quantities required for the plant.

Piston machines usually have higher overall efficien . The key advantage can be seen at low operation powers, which are associated with large leaks in the blades of low power turbines. At low power (up to 1 MW) Stirling engines are preferable to engines operating under the Rankine cycle, thanks to the simpler design, greater efficien , and higher unit power. Moreover, for Stirling engines, the choice of pressure and temperature regimes can be made independently, which is impossible for systems with a vapor-like working fluid. In space power installations, efficienc is the determining factor. Higher efficiency leads to decreasing of the required space allocation and weight of the refrigerator-emitter, since less heat should be carried away from the station.

For space conditions, it is possible to have a modular design of the station, when the required power is composed from a certain number of standard units (Figure 7) [14].

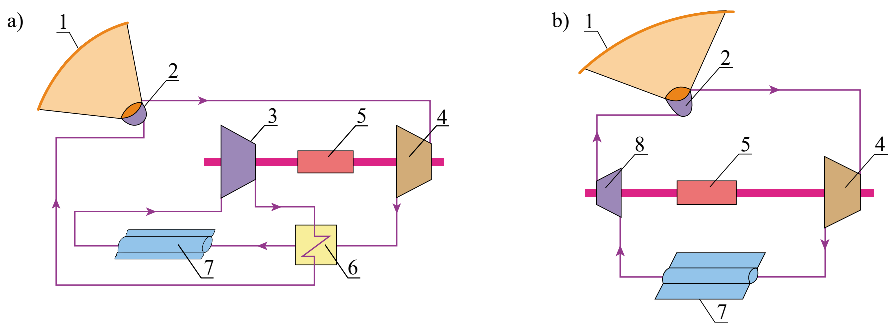


Figure 6 – Schematic diagrams of solar gas-turbine and steam-turbine power plants:
1 – concentrator; 2 – solar boiler; 3 – compressor; 4 – electric generator;
5 – turbine; 6 – regenerator; 7 – refrigerator-emitter; 8 – pump

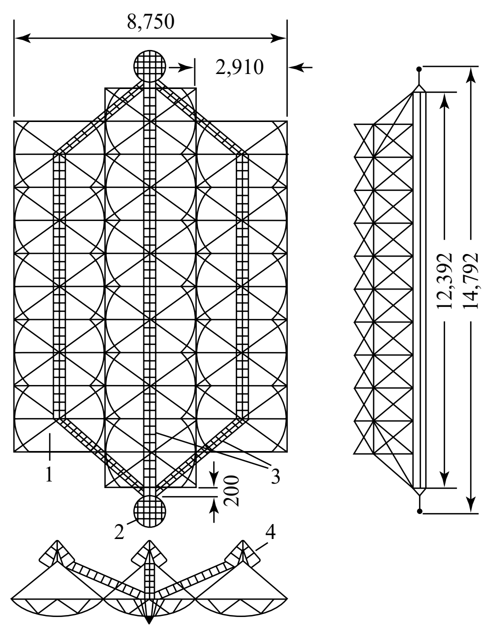


Figure 7 – Diagram of a 16-modular SSPL with a gas turbine converter (dimensions are indicated in metres):
1 – concentrator; 2 – antenna; 3 – power switchboards; 4 – refrigerator-emitter

Table shows the design parameters of the space thermal power installations with machine-based electrical converters [15].

Table – Design parameters of space thermal power installations with machine converters of thermal energy

Convertor type	Working medium	Output power, kW	Efficienc factor, %	Weight, kg	Concentrator diameter, m
Gas reciprocating with Stirling engine	Helium	5	20	258	5.7
Gas turbine	Helium-xenon	2–10	15–22.7	–	9.2
Steam turbine	Mercury	3	12	236	9.6
Steam turbine	Rubidium	15	24	454	13.5

An alternative option of the generation unit in a thermal power plant may be a magnetohydrodynamic generator (MHD generator) (Figure 8) – a device in which the energy of the working medium moving in a magnetic field is transformed directly into electrical energy. The principle of operation is based on the phenomenon of the electromagnetic induction, i.e., a current arises in a conductor, which crosses the lines of magnetic field. The conductor in the MHD generator is the operating medium itself – the flow of charges occurs in it during the motion across perpendicular magnetic field. Electrolytes, liquid metals, and ionized gases are typically used as working fluids in MHD. Solar thermal energy is used to accelerate and ionize the working fluid

To create the electrical conductivity of a gas, it must be heated to a thermal ionization temperature (about 10,000 K). For operation at lower temperatures, the gas is enriched with alkali metal vapors, which makes it possible to lower the temperature of the mixture to 2,200–2,700 K. The speed of the plasma in the generator channel after acceleration during the passage of the nozzle is about 2,000 m/s.

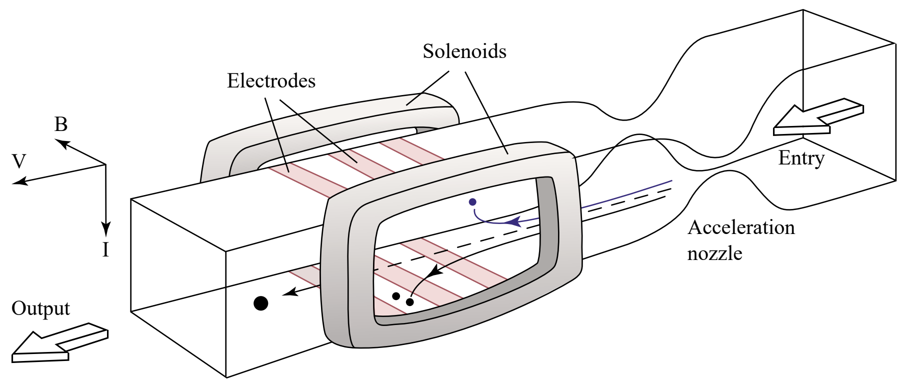


Figure 8 – Magnetohydrodynamic generator

Compared to the operation of steam and gas turbines, the advantage of a system with the MHD generator is the absence of rotating parts. This has significant impact on the reliability of the system. Furthermore, MHD generators can be used in power plants with combined cycles. In this case the total electrical efficienc of the plant can be as high as 55–60 %.

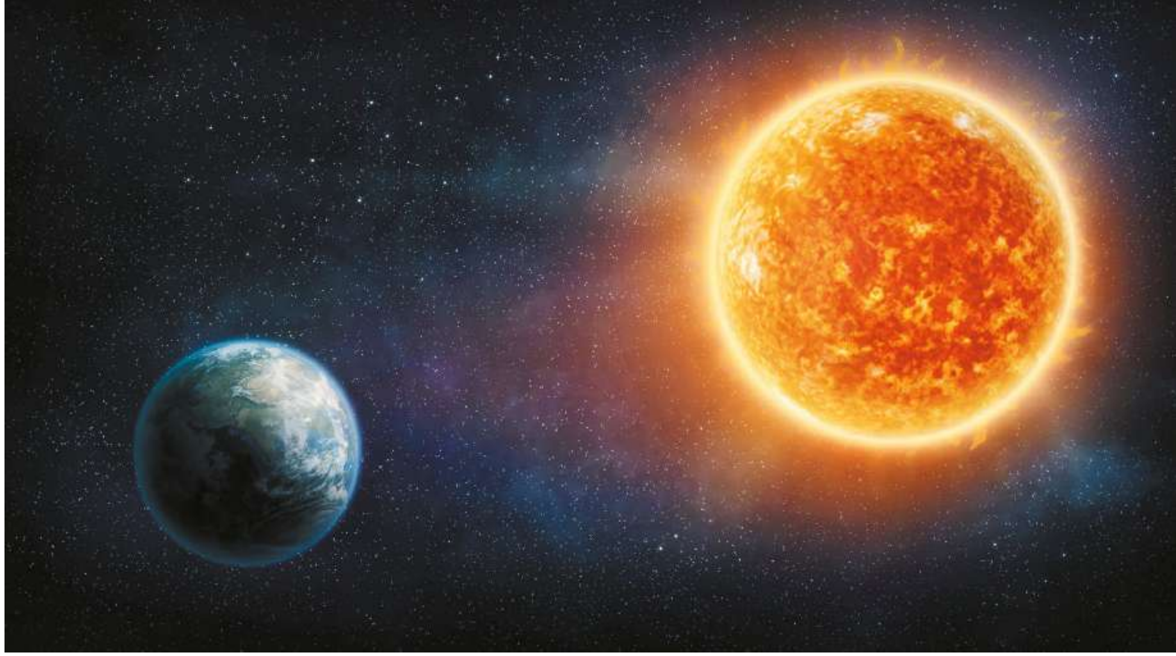
Thus, there are many ways to generate electricity from the solar radiation in space. All of them are rather profoundly studied only theoretically and on low-level laboratory prototypes. The exception is the PV systems, which is currently used to power the satellites and the ISS [16].

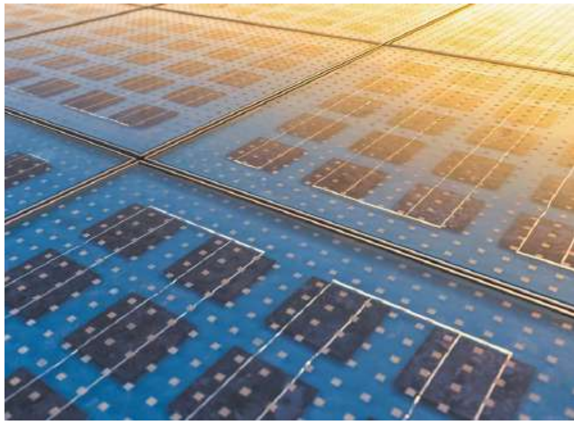
Of the described alternatives, the most optimal solutions with respect to the efficiency are thermal power plants with machine converters. The efficienc of such stations reaches 36 %, and during the passage of combined cycles, including integration of the MHD unit, 60 % and above (while the efficienc of PV plants is at the level of 14–20 %, and that of thermoelectric power plants is about 2 %). If to compare the specific mass values of power plants, photovoltaic power plants are more attractive, for which this indicator is 1.4–3 kg/kW (for stations with machine converters – 30–78 kg/kW, for thermoelectric stations – hundreds of kg/kW). The service life of PV panels is about 30 years, and of thermal power plants – at least 40 years.

Influx of solar radiation in orbit has cyclic nature with a period of 1.5 hours. It leads to the outcome, that patterns of power generation and power consumption cannot be simultaneous. Consequently, there is a need to use additional energy storage systems, which for the need of ISN “Orbit” are going to have quite large capacity of the peak power reaching 10 MW. Currently, the most widely used solution in energy storage systems is high-capacity batteries, which have low efficienc and high installation cost due to the presence of rare materials in their structure. Heat accumulators are simpler and less-costly in design and have a much longer service life. They have been studied, tested, and operated at all terrestrial steam-turbine solar power plants (they provide round-the-clock operation of the station with the possibility to produce electricity even at nighttime). Accordingly, high-capacity heat storages are economically more preferable than chemical-based solutions. Consequently, it is easier to ensure constant electrical power output from a thermal conversion power plant and adjust it, based on the consumption requirements.

At the same time, thermal power plants are more complex in their structure, there are additional thermal equipment (due to the presence of an intermediate energy conversion) and auxiliary systems. This means a higher risk of equipment’s failures due to the presence of a larger number of components.

A promising direction is also the technology of decomposition of water by solar radiation into hydrogen and oxygen by any known method, followed by direct or indirect “burning” of hydrogen and oxygen in any of the known types of power plants, for example, gas piston [17] or using hydrogen fuel cells [18], in which chemical energy is converted into electricity without burning. In this case, a part of hydrogen and oxygen can be consumed in orbit, and a part can be delivered to the Earth’s surface for use in power systems and transportation.





These technologies are ecologically safe both in orbit (they can even be used inside space settlements – EcoSpaceHouses) and on Earth, since distilled water is the product of the combustion of fuel within the technical solutions. In addition, the cyclic nature of solar lighting in orbit will not affect the operation of such power plants and will not require energy storage devices – thermal or electric, since storage uses two components (fuel and oxidizer).

At the same time, terrestrial ecology will not be disturbed – the water taken from the planet will return to it after passing through the energy cycle. With the delivery of water to the orbit in the number of millions of tons, and back in form of separated hydrogen and oxygen, there will also be no problems when using the General Planetary Vehicle (GPV) as a geocosmic transport system due to the fact that its ballast system can be filled only with water [1]

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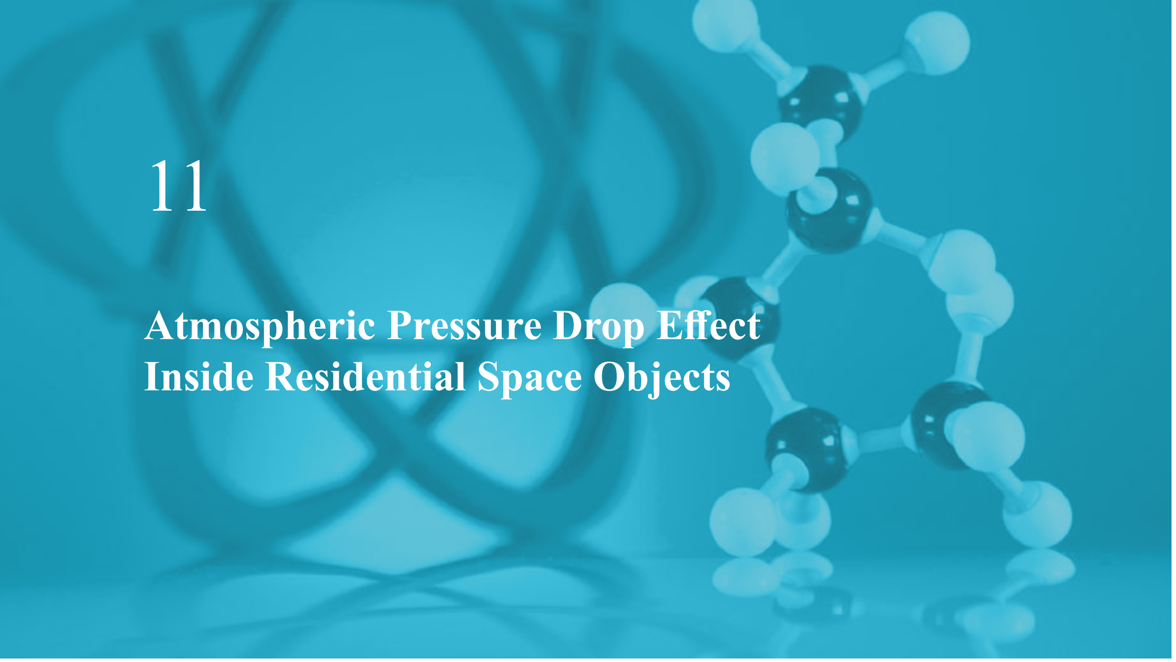


11

Atmospheric Pressure Drop Effect Inside Residential Space Objects

11.1 Introduction

Extensive scientific work on space exploration has been carried out in the last decades [1]. The design and creation of inhabited objects creates a lot of complex problems at the intersection of various scientific disciplines. The design purpose is to minimize material capacity and cost and to provide comfortable living conditions. One of the possible ways to address these issues is to reduce the atmospheric pressure inside a space object. Considering the direct dependence of the shell's strength on the internal pressure, the reduction of the developed pressure by half will reduce the load on the shell of the space structure by 10 t/m2 to 5 t/m2 [2]. Reducing the load on the carriers' shell of an EcoCosmoHouse (ECH) will proportionally reduce its material capacity and, accordingly, can save billions of dollars in costs of the high-strength materials and in the delivery expenses to the orbit and construction work in space [2].

However, it should be taken into account that the reduced pressure will affect the comfort of living conditions inside these inhabited structures. When the atmospheric pressure is decreased, there are violations in the functioning of all systems in living organisms. Hypoxia occurs in humans and animals, breathing frequency increases, and causes associated physiological changes [3, 4]. On the contrary, low pressure has a positive effect on the plants' growth [5, 6]. In case of a long stay under

the new conditions by humans and animals, the negative factors can be partially compensated thanks to adaptation, and the comfort of living under low pressure can be compensated by increased oxygen content. However, such a technological solution will limit the practical use of the space system and impose special requirements for combustible materials, such as wood.

The aim of this research is to study the possibility of reducing the pressure and increasing the oxygen content in the atmosphere of a space settlement for living creatures and structures.

The following tasks were set for the study:

- to consider the possible pressure drop in the autonomous ECH biosphere as a model of space settlement on the Earth's orbit [2] without significant negative impact on the normal vital functions of living organisms;
- to study the effect of increased oxygen content on self-ignition of materials
- to determine the required percentage of the other gas components of the atmosphere at the lowered pressure (argon, nitrogen, carbon dioxide, and other gases);
- to study the effect of rapid changes in the gas composition and pressure on living organisms;
- to study the ways of accelerating the adaptation of organisms;
- to calculate the impact of pressure drop on supporting structures of ECH.

Section 11.2 discusses the peculiarities of life activity of living organisms in hypobaric and hypoxic conditions. Section 11.3 analyses the possible solutions to the emerging states in the inhabitants of space objects at a decreased atmospheric pressure. In section 11.4 authors analyse the impact of hypobaria. In conclusion and perspectives, the possible solutions are discussed.

Investigation included literature revise and the appropriate calculations to analyse the main outcomes of the decreased atmospheric pressure, from the point of view of the human life support and financial indices

11.2 Influence of Low Pressure on Living Organisms

The cost of space objects is always estimated during the design process. Low cost and high strength per each unit are the main criteria in construction materials selection [1]. The economy of space structures with high material capacity and cost becomes especially important in case of the large inhabited space structures [7, 8]. To solve this problem (for example, in case of ECH), it was proposed to induce a two-time decrease in pressure in the internal space of the structure.

Atmospheric pressure on Earth, where people feel comfortable and their bodies' state is not negatively affe ted, equals to 1 atm or 101 kPa. Table shows the average chemical composition of the air across the Earth's surface [9].

Table – Chemical composition of the air at the Earth's surface

Gas	Volume concentration, %	Partial pressure, kPa
Nitrogen	78.1	79.1
Oxygen	20.9	21.2
Argon	0.934	0.946
Carbon dioxide	0.0314	0.032
Neon	0.00182	0.00184
Helium	0.000524	0.000531
Methane	0.0002	0.000203
Krypton	0.000114	0.000116
Hydrogen	0.00005	0.000051
Nitric oxide (I)	0.00005	0.000051
Xenon	0.0000087	0.000009

Equation 1 indicates a decrease in the partial pressure at a decrease in atmospheric pressure [10]. Due to the peculiarities of human physiology, it is the main component of normal gas exchange in the alveoli of the lungs:

$$p_g = \frac{p_a n}{100}, \qquad (1)$$

where p_g – gas partial pressure, kPa;

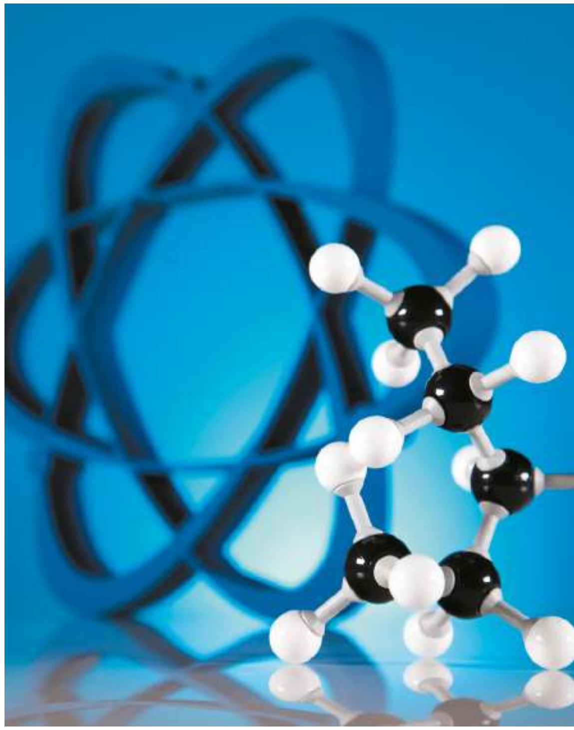
n – gas content, volume %;

p_a – atmospheric pressure, kPa.

The gases in the hollow organs begin to expand rapidly as the barometric pressure drops [11]. Gases in the liquid environments form bubbles of various sizes, which gradually squeeze the nerve endings of tissues and cause pain, usually in the muscles and joints. The accumulation of free gas inside and around the blood vessels can cause failures in the blood supply of the majority parts of the body [3].

In case of a more serious hypoxia, heart function becomes impaired which can be seen by occurrence of tachycardia, arterial pulsation (carotid, temporal) and electrocardiogram changes [11]. In such situation, human body experiences serious problems of motor and secretory functions of the gastrointestinal tract and changes in the peripheral blood content. The main reason for the symptoms described above is the lack of partial oxygen pressure in the lung alveoli [12].

However, a person may continue to exist and be active in a permanent low pressure (up to 47.5 kPa) environment despite the danger of a sharp pressure drop [13]. For example, people do live well in mountainous areas with significantly lower atmospheric pressure and the partial oxygen pressure in comparison with the normal conditions. Normal life activity of organisms in such conditions is possible with the help of adaptation.



Thus, to evaluate the possibility of a human to survive at a low pressure, it is required to study the mechanisms of organism's adaptation. The main characteristics of the adaptation is increase in the hemoglobin quantity and, consequently, of erythrocytes in the blood [14]. The number of erythrocytes increases due to the fact that the process of hematopoiesis intensifies, a large number of reticulocytes (young, immature erythrocytes) are observed in the blood. Under low pressure conditions, hyperventilation is activated, and gas alkalosis and hypocapnia occur as a result of this process. Also, some changes in the acid-alkaline equilibrium happen as a result of acclimatization process. The reaction of the equilibrium composition is being shifted to the acid side. Breathable air volume therefore increases [13].

Ventilation of the lungs usually increases in a few week time after transfer into the hypobaric environment. This is happening because the kidneys compensate for strong alkalosis by extracting bicarbonate ions (HCO_3^-), which leads to increasing concentration of ions H^+ in the blood [13]. In addition, the following changes are commonly occurring in the body: the pH of cerebrospinal fluid, surrounding the centre of respiratory control in the bone marrow, returns to the normal levels, despite the serum alkalosis; carotid glomus hypersensitivity to hypoxia is observed; high response of respiratory control centre to the content of CO_2 is present [11, 14].

Organs and tissues gradually normalize their functioning because of the adaptation mechanisms [15].

Adaptation can be accelerated in different ways: injection of serum of animals which have been subjected to the atmosphere with the lowered pressure for a long time; alternatively, intake of small doses of arsenic and iron. As it was found out, better results have been achieved with the addition of the acidic products (for example, ammonium phosphate, citric acid in sugar syrup) [16].

The risk of ignition of the combustible materials will increase once the oxygen content increases. However, scientifi data have suggested successful experience of saturation the atmosphere of the spacecraft with oxygen up to the level of 60 % [1, 17, 18].

Thus, based on the review of the available studies, it is clear that pressure drop can decrease the material consumption halving and, subsequently, the cost of the space inhabited objects. However, it may cause dysfunction in the ecosystem if the proper compensatory responses are not introduced to reinstate the correct partial oxygen pressure and other parameters of the healthy gaseous environment.

11.3 Ways to Compensate Negative Impact of Low Pressure on Living Organisms

The diameter of the object and materials should be noted for ECH supporting structures. If the diameter of the cylindrical part of the space house is 200 m, pressure decrease by 0.5 atm will reduce the total breaking force of the load-bearing

structure by 157,000 tons, if the diameter is 500 m then it will reduce the load by 981,000 tons. The mass of ECH load-bearing structure with the diameter of 200 m can be reduced by 3,500 tons, and if diameter of ECH is 500 m the weight can be reduced by 45,000 tons, using high-strength materials with the price up to 100 USD/kg, such as carbon polymeric composites, Kevlar, and alternatives. Cost savings on delivery of high-strength materials to the orbit using launcher vehicles (the cost of delivery is about 10 mln USD/t) for a 200 m diameter space house will be 35 bln USD, for a 500 m it will be 450 bln USD (when the cost of transportation to orbit is reduced to 1,000 USD/t). However, once the General Planetary Vehicle (GPV) is used for the transportation process [2], it will be 3.5 mln USD and 45 mln USD respectively. Based on these calculations, the pressure drop will minimize the cost of materials and their delivery expenses for the construction of ECH. However, there will be a large number of living organisms in ECH that are dependent on environmental factors. Therefore, the impact of the lowered pressure on humans, animals, and plants should be assessed.

Four gases should be considered while considering changing the gas ratio in the atmospheric air of space objects, i.e., the gases which have the highest mass percentage in the gas mixture and affect the vital functions of all living organisms. These gases are oxygen, nitrogen, argon, and carbon dioxide.

The partial pressure of all gases will decrease when the pressure is halved to 50.7 kPa. The main negative impact on human and animal organisms will be low partial oxygen pressure and, consequently, the appearance of symptoms mentioned in the review. To prevent the problems, the volume fraction of oxygen must be increased to 41.9 % according to the equation (1) to preserve the normal partial oxygen pressure.

Based on equation (1), the gas medium should include carbon dioxide in the volume fraction of 0.063 %. Its partial pressure should be the same as normal conditions on Earth, because CO_2 affects the brain's respiratory centre and participates in the respiratory process.

The remaining 58 % should be completed with inert or almost inert (e.g., nitrogen) gases [18]. This is essential due to their low weight and the inability to have a negative impact on living organisms [18]. The closest approximation to the normal terrestrial conditions can be achieved with the use of a mixture of argon and nitrogen. Nitrogen content can be minimized because it does not participate in vital processes of humans, animals, and plants [14].

It takes three days to adapt to the low pressure conditions, starting from 0.7 atm (530 mm Hg). To avoid negative consequences, we have developed methods of human transition from a normal atmosphere to an atmosphere with excessive oxygen content and low pressure, as was discussed in [11, 15]. Mechanism of such methods is to remove the nitrogen dissolved in blood and tissues during desaturation process. A person needs a few hours to breathe pure oxygen at normal pressure, or it is possible to slowly drop the absolute pressure [19].

A pressure drop of 0.5 atm (380 mm Hg) has a positive effect on plants. Investigations have confi med that low pressure reduces the intensity of dark respiration, which is beneficial to the production process [6, 20]. Growth of plants' shoots and roots in hypobaric conditions (50 kPa) exceeds growth of plants in normal atmospheric pressure conditions [5].

Animals that use hemoglobin as a mechanism for oxygenation will need the same amount of oxygen as humans, as discussed above [7]. Primitive animals (arthropods, mollusks, etc.) are less dependent on oxygen content than the higher creatures [8]. They have limited oxygen use due to the primitive structure of all organs and partial absorption of oxygen through the skin.

Increasing oxygen concentration up to 40 % solves the hypoxia and related cardiovascular and central nervous system disorders.

However, there is a risk of self-ignition of materials in such chemical composition. There is no risk of self-ignition of combustible materials, when 23.5 % equals to oxygen concentration in the air [21]. In case of a higher oxygen content, high risk of the ignition will be created [21].

For example, based on the fire safety requirements in the spaceship "Union" [17], the oxygen content of about 40 % is allowed. The following items on board of the spacecraft are under danger of catching fire due to self-ignition: electronic devices, cables, and various technical equipment items. Typically, fi e-resistant materials should be used when oxygen concentration is high. And if combustibles are allowed, then only in small quantities and after careful analysis. Using coatings or impregnation, combustible materials can be isolated from the direct contact with oxygen by non-flammable or low thermal conductivity materials to decrease the temperature in the event of fire [1]. However, in the environment of ECH, it will be impossible to fully avoid combustible materials or to create perfect insulation due to the presence of plants, including dry vegetation as part of the life-supportive systems. The solution of this problem can be the development of a list of allowed materials and coatings, as well as the strict operating rules in the zones with combustible materials and high concentration of oxygen.

11.4 Feasibility of Using Low Pressure in ECH While Estimating the Cost of Its Components' Delivery by Missiles and the GPV

The total weight of ECH to accommodate population of 5,000 people was estimated at 400,000 tons. It includes 7,000 tons of a load-bearing shell, 90,000 tons of antimeteoric and antiradiation protection, 160,000 tons of fertile soil, 70,000 tons of water, and 5,000 tons of air. As can be seen, the load-bearing shell is the lightest part of ECH, with its weight of about 1.75 % of the total weight, which means, even a two-times saving on material capacity of the load-bearing shell will result in overall savings of only 0.875 %. Another 0.625 % of weight (2,500 tons) will be made up by decreased air demand. The evaluation should be done to whether it is worthwhile to create an environment with low pressure and high oxygen content, which will increase the risk of fire and require a number of additional firefightin measures for the sake of such economy [2]. If the space industry is built on the basis of non-rocket transport, it will be possible to avoid pressure drop inside ECHs and to have the gas composition and pressure conditions very similar to the terrestrial ideal parameters. When the transportation to the orbit at the first stages is carried out by the rockets and the cargoes for ECH (with the total weight of about 500,000 tons per one house) are delivered by the GPV, the cost of each space house can be lowered thanks to the effective transportation solution

For example, the volume of air in a cylindrical ECH with internal diameter of 200 m (and internal length of about 500 m) equals to 15.7 mln m3, and the mass of air under normal pressure and density will be 18,800 tons. If the pressure is decreased by half, the weight will drop to 9,400 tons. The delivery cost of this weight from Earth to the orbit by rockets will be around 190 bln USD and 94 bln USD, respectively, and in case of delivery by the GPV it will be 19 bln USD and 9.4 mln USD, respectively. Air volume in cylindrical ECH with internal diameter of 500 m (at internal length about 1,000 m) will be 196 mln m3 and air weight at normal pressure and density will be 236,000 tons with the weight of the halved pressure decreasing to 118,000 tons. Then the delivery cost by rockets will be 2.36 tln USD and 1.18 tln USD, respectively, and by the GPV it will be 236 mln USD and 118 mln USD, respectively.

The physiology of humans, animals, and plants shows differences in their adaptation to the conditions with low atmospheric pressure.

Pressure drop has a positive effect on vegetative mass growth and development for plants. However, no investigations have yet been conducted on the effect of hypobaria and oxygen increase on the synthesis of alkaloids, flavonoids and other biologically active substances.

Humans and animals, due to their active gas exchange with the environment, are affected by any change in external conditions. Therefore, hypobaria and, as a result, low partial oxygen pressure, negatively affect the whole state of the body, especially, as far as related to affecting the central nervous and cardiovascular systems. The solution to this problem is to increase the oxygen content of the gaseous environment up to 40 % and to introduce a gradual adaptation with the provision of desaturation.

All of these solutions appear to be costly, so it is worth assessing the peculiarities of such changes, that manifest themselves in reducing the load on ECH load-bearing structures.

11.5 Conclusion and Future Work

Humans and higher animals are most negatively affe ted by the chemical and physical changes of the air parameters due to the complex mechanism of gas exchange between tissues and the environment. However, the adaptation of humans and animals can be gradual and achieved by increasing of the oxygen content in the atmosphere.

The important thing is a higher probability of spontaneous ignition of materials with oxygen concentration exceeding 30 %. It also requires careful monitoring, which is difficul to maintain in an ECH environment. Therefore, the appropriateness of pressure drop and the benefi s derived therefrom should be critically evaluated.

Based on the calculations within the framework of this research, we can conclude that if air for ECH is delivered into orbit by rockets, transportation cost savings from the pressure drop for a 200 m diameter house will be 95 bln USD, for 500 m it will be 1.18 tln USD, which are substantial numbers. If air is delivered to the orbit by the GPV, the savings on transportation will be 9.5 mln USD for a small house and 118 mln USD for a bigger ECH. Savings will be insignificant (compared to the cost of ECH itself). The same conclusions can be drawn regarding the construction of ECH using the GPV. Therefore, it is reasonable to create a comfortable normal pressure in ECH environment, which should be equal to 760 mm Hg or at the level of mountainous areas of the planet (about 700 mm Hg). In the future work, we will study the influence of low pressure in the ECH atmosphere on groups of organisms that will potentially enter an enclosed ecosystem; create and test a breathing environment selected from a literature review; develop methods of control over self-ignition materials and methods of their protection.

It was proposed to construct ECH in the form of a "matryoshka" – a small cylindrical house with a diameter of 200–300 m, where people live at atmospheric pressure, placed on the axis inside a large cylindrical house with a diameter of 400–500 m, where all the flora and fauna are placed in the atmosphere with a pressure of 380 mm Hg. Such a space settlement will be free of disadvantages described above.

People will live there in the familiar Earth atmosphere, where they can get about without spacesuits and pressure chamber. The other part of the biosphere with flora and fauna will be in the interval between the cylinders. This will twice unload the load-bearing shells of both ECH components, since the pressures inside and outside thereof will differ by 380 mm Hg, i.e., the load will be 5 t/m^2. At the same time, the ignition danger will be avoided. Agricultural productivity in the adjacent house will be higher than inside the normalized conditions compartment. In addition, the meteorite and radiation protection will be improved. As can be seen from the ideas, that aggressive space environmental items will have to pass through three barriers: force protection and a thick layer of soil in both houses, as well as the 100 m thick air environment between them.

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12

Design Elements of Residential Space Cluster EcoCosmoHouse and Their Performance Assessment

12.1 Chapter Overview

The research provides the comprehensive study of a residential space cluster EcoCosmoHouse (ECH) from the perspective of the integral part of the orbital and infrastructural industrial and residential complex – Industrial Space Necklace "Orbit" (ISN "Orbit"), as well as a centre of crystallization of the space industry. This research describes possibility of creating within these multifunctional clusters living conditions for humans, which are different from the commonly represented on the Earth: gravitation, atmosphere and living environment. The special attention has been given to the modelling of Earth's biosphere inside ECH, including specific elements, such as: flora, fauna, microflora, and microfauna. The paper describes the design of the space residential cluster, including assessment of the approximate costs and required construction materials in use. Moreover, the paper provides the comparison between ECH and existing near-Earth systems for human living, such as the International Space Station (ISS), using the following criteria: living comfort, construction expenses, and cost of maintenance.

12.2 Technical Challenges of Industrial Space Necklace

During industrialization of the near space, the first stage should include the creation of ISN "Orbit". It is an orbital system, combines transportation and infrastructure facilities with the industrial and residential complexes, covering the planet in the equatorial plane and having an appropriate length of 42,567 km, considering its height of 400 km. Construction process should begin from the first launch of the General Planetary Vehicle (GPV) [1].

Space-based industry should be serviced not only by the automated systems and robots, but by limited number of people. Requirements for the service personnel should be significantly reduced in comparison with the current Earth-based industry requirements. Nowadays, there are about a 1 bln specialists working in the industries, including transport, power systems, and communication and information technology. Maybe, in the future, the demand in work force will drop by 1,000 times to 1 mln specialists. The number of the tourists and rest travelers to the near space orbit will be approximately the same as the number of the service personnel, thanks to the possibility of creation in the outer space of the recreational complexes with better conditions as compared to those on Earth. Based on the combination of the needs, discussed above, it would be necessary to create new types of residential space settlements – ECH. These solutions will provide possibility for millions of people to live, work, have rest, have therapy and undergo treatments (Figure 1).

The cross-sectional dimension of these structures is up to 500 m, to optimise their aerodynamic performance, which otherwise would impede the entire industrial complex due to the presence of gas medium at this altitude, although its

Figure 1 – Design of the part of Industrial Space Necklace "Orbit" with double-type torus-shaped ECH (variant), to which flies the expanding GPV (on the right) with passengers and cargo nacelles (visualisation)

density is nearly negligible. At the altitude of 400 km, the density of the gas will be 3×10^{-12} kg/m^3.

Single ECH will provide temporary residency for a couple thousands of people, which will replicate current community of villages, but using innovative technologies in their development. Furthermore, the best part of the terrestrial biosphere will be recreated in ECH, including elements, such as atmosphere, variety of landscapes, living organisms, soils, biogeocenosis, and water ecosystems. Gravity will also be created using centrifugal forces to ensure the most comfortable living conditions. Proposed approach will ensure that the proper living conditions are provided to the humanity, including illumination in the natural spectrum, optimum temperature, stable air pressure, humidity, etc.

12.3 Overview of Requirements for EcoCosmoHouse

Proper living conditions should be created using combination of the technological solutions to ensure proper operation of each system.

Comfortable gravity. Gravity on the orbit can be created using centrifugal forces. There is a possibility that the most comfortable gravity would be similar to the weaker one existing on the Moon or Mars and with the free fall acceleration of about 2 m/s^2, i.e., five times lower than on Earth. For such conditions, the equivalent weight of the adult would be about 15 kg.

Comfortable atmosphere with air pressure, gas composition, humidity and temperature:

- **pressure in the atmosphere of ECH.** There is a possibility, that the comfortable air pressure on the orbit will be similar to the value in the mountains on Earth. For example, it can be two times lower, reaching the value of 0.5 kgf/cm^2, or 5 t/m^2. Reduction of the internal pressure by two times will also reduce the load on the body of the space house and increase its reliability and operating life with significant reduction of the cost
- **gas chemical composition.** In order to avoid oxygen starvation with the reduced pressure environment, the oxygen content in the air can be doubled, up to 40 % compared to the 20 % of oxygen on Earth. However, the oxygen content cannot exceed the upper value, at which self-ignition of various combustible substances used in the interior of ECH, for example, wood, can occur. The content of other gases (nitrogen, argon, neon, carbon dioxide, etc.) should also be optimised. Moreover, the house might not have any zones with stagnant air, i.e., continuous airflow should be arranged. There are several ways to organise it either by means of convections or with the forced flow by special fans;
- **air humidity.** Living organisms, such as people, animals, and plants, get moisture not only from food, but also from the air. Thus, the humidity of the atmosphere

in a space house should be optimal, e.g., equaling to 55–60 %, throughout the day and entire year. If necessary, if can be adjusted on a day-to-day or annual bases;
- **air temperature.** There is a possibility to create an optimum temperature environment in the ECH with the annual temperature fluctuating within 21–25 °C. Similar to humidity, the temperature range can be adjusted beyond the optimal values.

Duration of the day and the year. The concepts of the day and the year on the orbit lose their significance, as ECH will make one revolution around the planet in about 1.5 hour, which will result in 16 revolutions during the standard daytime, having same number of sunrises and sunsets. Thus, a day and a year can be of an optimal duration, differing from 24 hours and 365 days, respectively, which implies the use of the artificial lighting. For example, 24-hour biorhythm is forced upon and abusive for the vast majority of modern citizens, as it can be evidenced by the regular use of the alarm clocks.

Illumination. The comfortable illumination is necessary not also for the human population of ECH, but also for its plants and animals. The plants require the light intensity higher, than 1,000 lux for their healthy development. In addition, the light should meet the following criteria:

- **high quality.** Specific spectral composition of the light should be present at each growth phase of the plants. Thus, development of the green mass requires high presence of the blue spectrum, whereas yellow and red spectrums are necessary for the growth of the root system and the blossoming process. Green light spectrum stimulates the process of photosynthesis in the leaves with dense structure;
- **continuity.** Most plants gain strength and are able to bloom only when the duration of the daylight is higher than 14 hours, i.e., in the summer period. At same time, there are plants, which should be kept under the light for not more than 8–10 hours per day during blossoming. Taking in account the above mentioned, the illumination in ECH should be localised, depending on the ecosystem of the given section;
- **intensity.** Dimmed light might be harmful for plants. The ideal option for the light-demanding plant species is 100,000 lux, which is similar to intensity of the sun light. Nevertheless, the source of light in a space house should be the Sun, either thorough the systems of special mirrors and lenses or by means of conversion electro-magnetic waves into electrical energy.

Comfortable living environment for a human. ECH should contain full biosphere of the planet. Currently, biosphere includes proper living conditions for the human, created during evolution process over billions of years. The full diversity of the flora and fauna from the favourable for human life climatic zones of Earth should be represented in ECH. Presented diversity should also include the microflora and the microfauna – the soil biogeocenosis with thousands of species of microorganisms.

A kilogram of healthy fertile soil contains about a trillion of soil microorganisms of several thousand species. They are all necessary for the existence of flora and fauna in the terrestrial biosphere, including humans. The fertile soil on the planet is the immune system of its biosphere and it is vital for its health. When the living fertile soil on Earth will be killed and replaced with the dead, artificial soil, impregnated with herbicides and pesticides and richly fertilised with mineral fertilisers, this will be the end of the terrestrial biosphere – the one we all know and of which we are a part. At that precise moment, can easily break out a pandemic, capable of killing all the people within just a few days.

Healthy fertile soil is necessary to create comfortable and safe living conditions for a human in ECH. For example, the core of the human immune system is the microflora and microfauna within the intestine, which is mostly considered to be soil microflora [2]. Soil-based microorganisms work days and nights to feed us, give us a drink and even the treatment.

The biosphere of a space house should constantly generate oxygen, which is necessary for people and animals living there. ECH should also produce healthy food and process all wastes from vital activities of living organisms in humus. Humus, which represents insoluble salts of humic acids, is the basis of the fertility of various soils, including the most fertile soil on the planet – the dark rich soil [3]. They can be considered as “canned food” for plants, which can be open only with a special “can opener” – microorganisms, living in the soil. The microorganisms process humus into a soluble form to feed the plants, establishing with them a kind of symbiotic relationship. Furthermore, plants cannot exist without a symbiosis with mushrooms. Mushrooms live in the plants and, in addition, support the formation of the network of roots, which works as a communication medium for the plants.

Figure 2 presents residential and natural zone of torus-shaped ECH. Figure 3 depicts an example of the residential apartments. In the space zones with high meteoroid threat, living apartments and offices can be created inside the nacelles of the GPV, by which passengers and cargo are to be delivered to the orbit. These nacelles are hermetically sealed. They have their own life support systems, can sustain overpressure and have an installed access door. Therefore, even in the event of a depressurization of a space house, caused by a hit of a large meteorite, residents can escape by tightly closing the hatch.

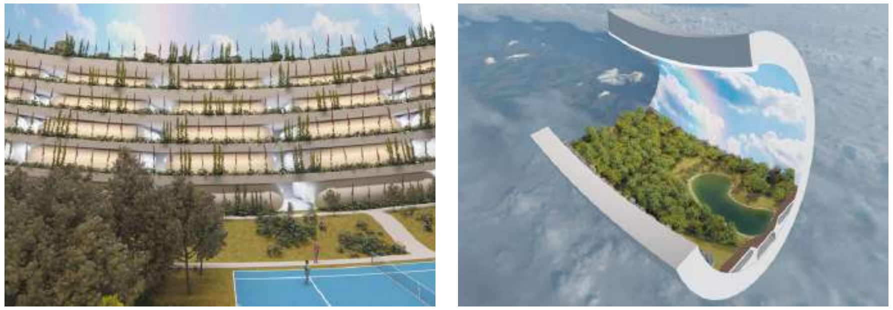

Figure 2 – Living (left) and natural (right) zones of torus-shaped ECH (visualisations)

Figure 3 – Residential apartments of ECH (variants) created in the nacelles of GPV (visualisations)

12.4 Technical Solutions

Protection against meteorites and radiation. The existing orbital stations do not provide full protection against meteors and radiation hazards, which exist in space and within the near-Earth orbit. For example, a drop of water at a speed of 20 km/s, which is common for the meteors, can penetrate a tank armor. Furthermore, cosmic radiation can kill a person in a few days, since its level is significantly higher, than it was at the exploded Chernobyl Nuclear Power Plant. The most effective protection measures against these threats are based on the thick multi-layered walls, not durable thin-walled screens. Such solutions may include combination of the foams, thick layer of the fertile soil, as well as thickness of the water and air.

Composition elements of ECH. The optimal technical solution for the space-housing cluster is a complex structure, which has the shape of a sphere, cylinder or a torus with a diameter of 200–500 m. They can be interconnected, but the rotational motions should be supplied to those structures. To initiate the rotation, space settlements can be paired and placed in-line, nearby or one inside another, and the linear electric motor will be capable to move them. There will be no needs to use jet engine in the system to obtain any circumferential velocity. For the paired system, one section will rotate in one direction and the other – in the opposite direction.

Load-carrying structure of ECH is made of a high strength material, being the least material consuming part of the system. For example, if made of composite materials produced by today's industry, the thickness of the load-carrying wall of such a huge structure should be just 3 mm. The most material-consuming part of the spherical house will be antimeteoritic and antiradiation protection, as well as a layer of a fertile soil – their total thickness will be up to ten metres.

The inner surface of the sphere, over porous meteoric and radiation protection, will be layered with the living fertile soil at least 1 m thick, forests, gardens, and meadows planted with their biogeocenoses. There also will be ponds with fresh and seawater, including their ecosystems there.

12.5 Financial Analysis and Conclusion

The approximate cumulative weight of the required materials to build a ECH for 5,000 people will be approximately 500,000 tons, which comprise of:

- structural shell – 2,000 tons;
- antiradiation and antimeteorite protection – 100,000 tons;
- fertile living soil (eco-black soil) – 200,000 tons;
- water, including fresh and salty types – 100,000 tons;
- air – 10,000 tons;
- building materials and structures, including interior of the apartments – 50,000 tons;
- other materials – 38,000 tons.

The delivery of these materials to the orbit for one ECH by the GPV will cost about 500 mln USD (about 1,000 USD/t). The cost of construction materials will be approximately the same as the delivery cost – 500 mln USD. Installation work in the outer space will require investments of about 1 bln USD. In total, space settlements to host up to 5,000 people will cost about 2 bln USD, which is about 75 times cheaper than the International Space Station, the costs of which exceeded 150 bln USD [4].

In conclusion, it can be demonstrated, that the budget spent today to transfer about a dozen astronauts to the orbit and placing them in life-threatening conditions, can support construction of the 75 space settlements for 375,000 people. In addition, such construction can provide more comfortable living conditions than on Earth.

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13

Options of EcoCosmoHouse Structural Solutions

13.1 Introduction

Protective shelters are the means which allow to create comfortable living conditions within the unsuitable to normal life environments. Protective covers are designed based on the physical conditions of ambient aggressive environment, such as ocean depths or surfaces of other planets.

The key issues in the outer space environment are the lack of the breathable air, zero gravity, cosmic radiation, and collision with the objects with high relative speed. As a result of recent space activities by civilization, a signifi ant amount of the space garbage has been inserted on the Earth orbit, which could endanger lives of orbit's citizens in the future. This garbage includes broken pieces of the satellites, hard particles of the rockets' shells, left behind tools, and other items. The exterior shell of EcoCosmoHouse (ECH) [1] has to protect people from all of the above-mentioned threats. Possible solutions for such shells are discussed in this research.

13.2 Review of Previously Proposed Concepts

All of the existing concepts of space stations for long-term accommodation of the groups of people were developed based on the mandatory creation of artificia gravity. Gravitational accelerations of 0.9–1*g* are considered as a comfortable value

for human's living environment. This requirement dictates the shape of such facilities or constructions. The commonly known shapes can be summarised as follows.

Stanford Torus was suggested to the NASA by the students of the Stanford University in summer 1975 to explore and discuss possible designs of for future space colonies. It consists of a torus, that is about 1.8 km in the outer diameter and 130 m in minor diameter [2].

Bernal Sphere is a type of a space station intended as a long-term home for its permanent residents, initially proposed in 1929 by J. Bernal. Bernal's original proposal described a hollow non-rotating spherical shell with 10 miles (16 km) in diameter filled with ai , with a target population of 20,000 to 30,000 people [3].

O'Neill Cylinder, also known as Island III, is a type of a space habitat proposed by Dr. G. O'Neill in his book "The High Frontier: Human Colonies in Space" [4]. It consists of the two counter-rotating cylinders 8 km in diameter and 32 km long, which are placed on the same axis.

Spherical and cylindrical shapes share similar operational principles and inner space arrangement. Based on this fact, the paper is focused on comparison of the two structural arrangements: toroidal and cylindrical.

Whipple shield is used to protect Earth orbit satellites against damage by relatively small objects [5, 6]. Figure 1 illustrates destruction of an object when it clashes with the firs layer of the Whipple shield. Remaining fragments are distributed, and they are not able to break through the main shell. Steel mesh could be used as the main layer of the shell, which will also act as the Faraday cage [7] and protect against electromagnetic radiation.

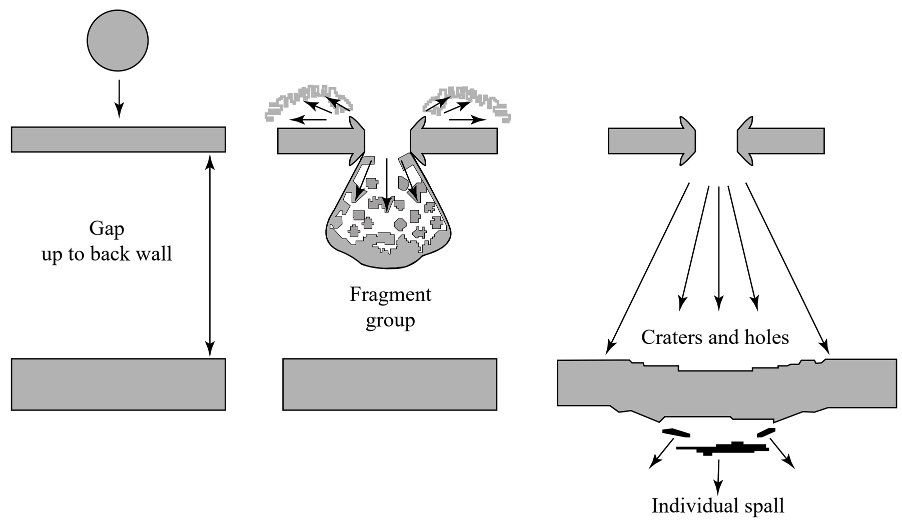

Figure 1 – Whipple shield operation

13.3 Structural Analysis of ECH

It is necessary to examine the structure of ECH with its cover made of a thin-walled shell and a topsoil layer with the thickness of 10 m, inside which utilities and other systems will be placed for the operation on the near-Earth orbit.

Many factors should be considered during development of such objects for the Earth orbit.

Abovementioned solutions, Stanford Torus and O'Neill Cylinder, included the following features: fully autonomous operation and absence of the links with other structures. However, connection possibilities of the structures with the other object, for example, Industrial Space Necklace "Orbit" (ISN "Orbit") [1], can be added, thus limiting some structural opportunities. Rotation axis of the shell should always be parallel to the rotation axis of the orbit, thus minimizing loads applied to ISN "Orbit" from precession effect (axis rotation perpendicular to the applied force).

Construction materials play an important role in the design of the space stations. The key parameters include delivery and installation costs. To reduce these costs, it is possible to rely on the strength to weight ratio of the materials during evaluation process. Carbon fibre reinforced polymers (CFRP), for instance, have this parameter ranging 0.53–1.125 MPa×m^3/kg. In comparison, high-strength steel has this value equivalent to 0.18 MPa×m^3/kg, while titanium alloys achieve 0.23 MPa×m^3/kg. Based on these parameters, authors proposed to use high-strength steel for ease of design process and subsequent output evaluation.

Elements of the outer shell should occupy minimal space for the transportation purposes. For instance, the main shape of ECH can be constructed using a solid fi m with minimum thickness, which ensure structural strength with the presented internal pressure applied. On top of this film, it is possible to apply additional multilayer structure to meet further requirements.

Two design diagrams were used to study material performance and structural characteristics of the ECH's structures for both torus and spherical designs. Toroidal design diagram was simplified to a shell with a radius of 500 m along the rotational axis a diameter of 50 m made of a solid revolving profile There is 1/4 of the whole model in Figure 2. Removed edges are symmetrical, thus limiting the numbers of finite elements for the analytical model

Analytical scheme for the cylindrical design was developed as a shell, separated into two subsections: cylindrical main body with spherical ends. Diameter of both parts was chosen as 500 m. There is 1/2 of the entire structure with removed symmetrical edges in Figure 3.

Loads applied in the study included dead weight of the shell, 10-metre-thick layer of the soil with density of 1.2 t/m^3 and internally applied gas pressure of 101 kPa, which fills the habitable area of ECH

High-strength steel, isotropic material, with a yield value of 1,400 MPa, was used for the analysis. Ultimate stress value of 470 MPa was taken to avoid shell destruction due to the accidental damages.

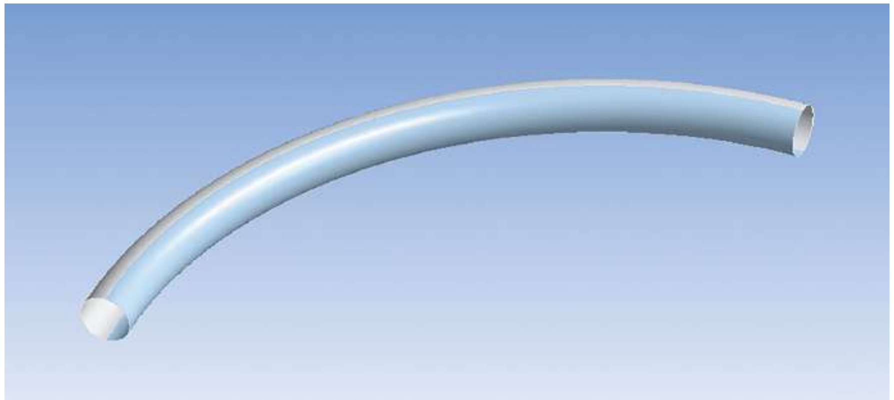

Figure 2 – Torus calculation model

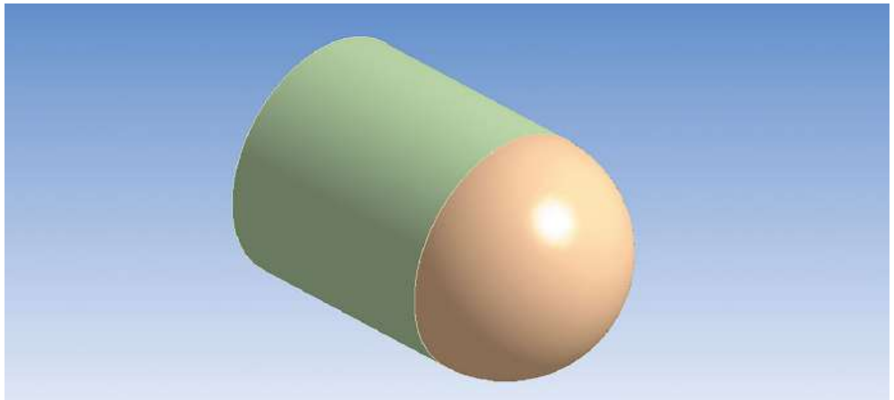

Figure 3 – Calculation model for the cylinder

Mathematical modelling included two stages. Stage 1 was designed to define internal pressure using distributed load of 101 kPa, which is applied throughout the inner surface of the shell. Stage 2 was creation of the artificial gravity with the free fall acceleration of 0.7g generated by rotation around the central line (axis). Rotation speeds of torus and cylinder differ due to the differences in their structural diameter defined by the main shape of the shell

Further analysis investigated impact resistance of the shell, which is constructed from the metal film and filled with the 10 m layer of the soil. The collision was modelled, considering objects flying in the outer space, made of the materials with density of 7,850 kg/m^3, with diameter of 200 mm and 400 mm travelling with the relative velocities of 10 km/s and 20 km/s, which creation of four calculation studies. Impact analysis was done using the section of the shell with dimensions of 10 × 10 m (Figure 4).

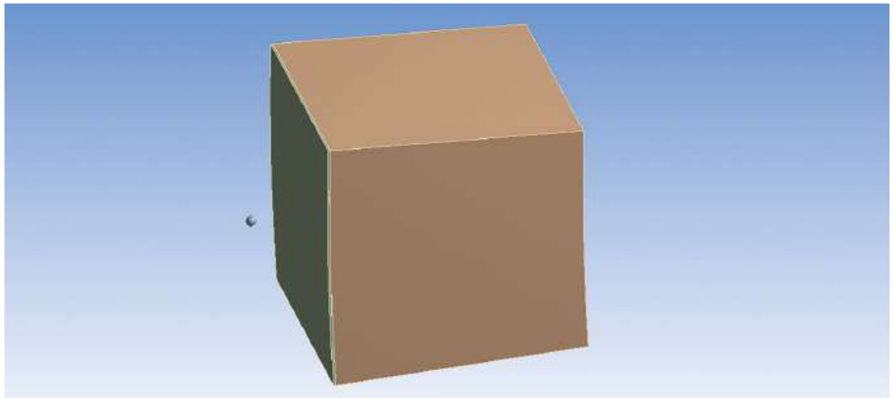

Figure 4 – Shell calculation model being hit by a high-speed object

13.4 Analysis of Results

A. Torus Shell

There was used 6.4 mm-thick steel shell of the torus in this study. Given thickness is sufficien to sustain the internal pressure of 1 atm. Maximal von Mises stress in the shell walls under impact of the applied internal pressure did not exceed 350 MPa (Figure 5).

Stage 2 included impact of the artificial gravity, generated by rotation at a speed of 0.11 rad/s, which generates centrifugal acceleration equivalent to 0.7*g*. Soil is located only over the outer walls of the torus and it is kept in place due to the centrifugal forces. In this case, maximal von Mises stress in the shell walls was equal to 3,600 MPa (Figure 6).

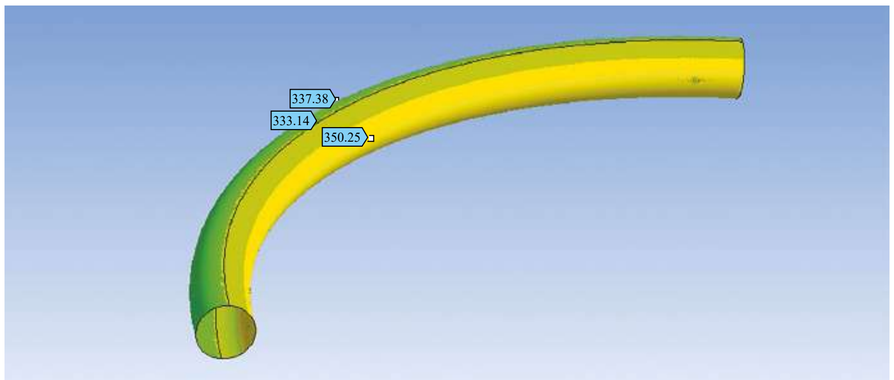

Figure 5 – Stage 1. Torus stresses

The main reason for such a high value is the presence of the bending moment, which was not included in the initial membrane-based theory of the shell's construction [8].

It is suggested to increase structural bending stiffness to decrease the peak stresses in the system.

B. Cylindrical Shell with Spherical Ends

Calculation 1 was conducted with equal wall thickness at the cylindrical and spherical segments. Second study was conducted with the addition of the artificial gravity, developed by rotation of ECH with the speed of 0.16 rad/s, which creates accelerations equivalent to 0.7*g*. There was chosen 88-mm-thick with respect to von Mises stress values being below 470 MPa with the presence of the internal pressure (Figure 7), as well as with the presence of the artificial gravity (Figure 8). Results showed, that the system includes a deformation difference with the shape of a step of 50 mm (Figure 9), at the connection point between the cylinder and spherical sections.

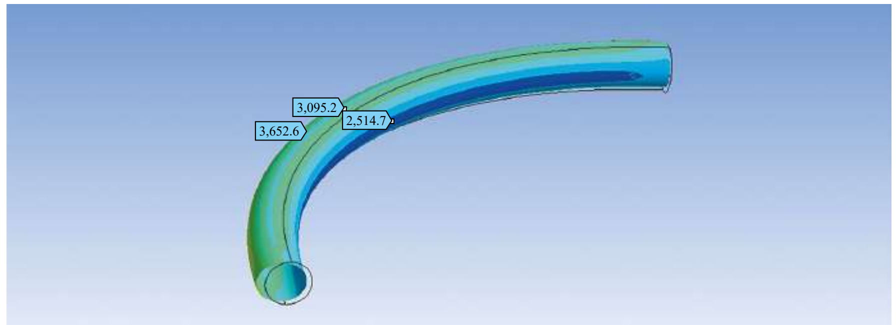

Figure 6 – Stage 2. Torus stresses

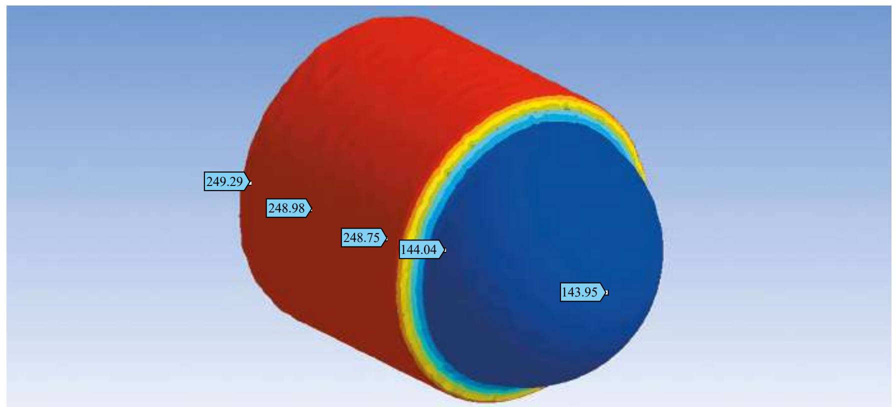

Figure 7 – Stage 1. Stresses in a cylinder with equal wall thickness

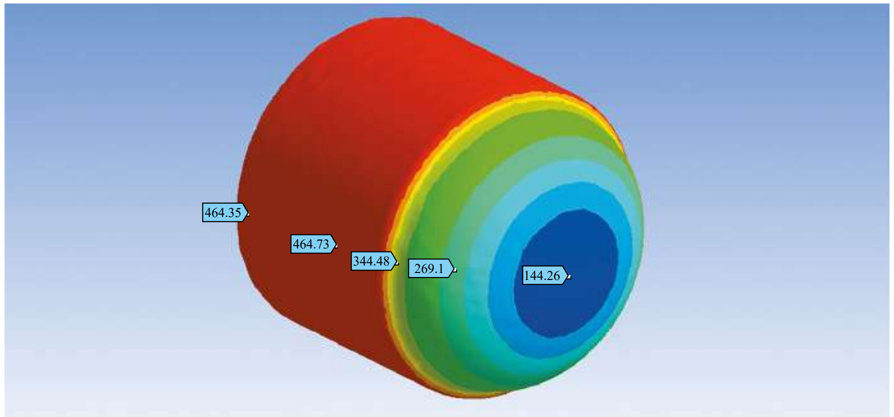

Figure 8 – Stage 2. Stresses in a cylinder with equal wall thickness

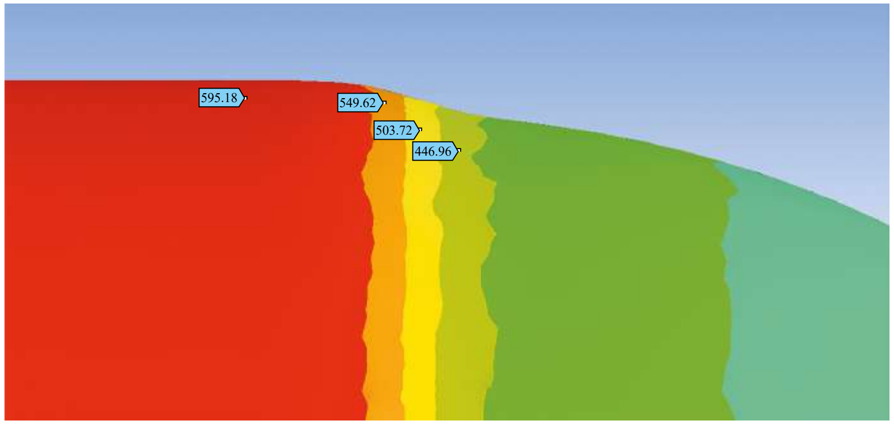

Figure 9 – Stage 2. Deformation difference in a cylinder with equal wall thickness

Calculation 2 was conducted using equations of the normal stress to avoid a step in all sections of the shell using equations (1) and (2), where thickness of the shell was set at 88 mm for cylinder and 44 mm thickness for sphere:

$$\sigma_{sphere} = \frac{PR_{sphere}}{2t_{sphere}}, \qquad (1)$$

where σ_{sphere} – radial stress in a spherical section of the shell;
P – internal pressure applied to the wall;
R_{sphere} – sphere radius;
t_{sphere} – sphere walls thickness;

$$\sigma_{cylinder} = \frac{PR_{cylinder}}{t_{cylinder}}, \qquad (2)$$

where $\sigma_{cylinder}$ – radial stress in a cylindrical section of the shell;
$R_{cylinder}$ – radius of the cylinder;
$t_{cylinder}$ – cylinder walls thickness.

These changes demonstrated inability to eliminate the step variation in the deformations, which increased to 65 mm (Figure 10).

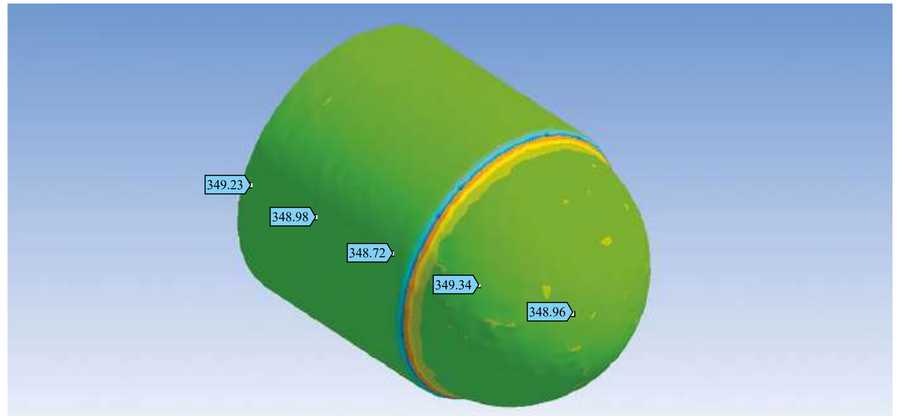

Figure 10 – Stage 1. Concentrators in a shell with the spherical wall thickness decreased by two times at the ends

Study number 3 was performed to evaluate radial deformation of the shells having different construction types. Equation (3) was used to calculate radial expansion for a cylinder:

$$\omega_{cylinder} = \frac{PR^2_{cylinder}}{Et_{cylinder}}\left(1-\frac{\mu}{2}\right), \qquad (3)$$

where $\omega_{cylinder}$ – radial expansion of a cylindrical shell;
E – elastic modulus of the material;
μ – Poisson's ratio of the material.

Equation (4) was used to calculate radial expansion for a spherical section:

$$\omega_{sphere} = \frac{PR^2_{sphere}}{2Et_{sphere}}(1-\mu), \qquad (4)$$

where ω_{sphere} – radial expansion of a spherical shell.

Using equality of equations (3) and (4), the revised ratio of the walls' thicknesses between cylindrical and spherical sections was derived, as shown in (5):

$$\frac{t_{cylinder}}{t_{sphere}} = \frac{2\left(1-\frac{\mu}{2}\right)}{1-\mu}. \quad (5)$$

Using high-strength steel, this ratio was calculated and equals to 2.4286.

Under this ratio, cylinder walls were designed as 88 mm thick, while spherical section was designed using thickness of 36.2 mm.

The results of the adjusted design allowed to eliminate deformation difference Internal pressure-based study demonstrated, that spherical shell has 350 MPa von Mises stress, that exceeds 250 MPa von Mises stress in a cylindrical section (Figure 11). However, second study with the artifi ial gravity, the stresses equality was achieved, which happened due to the extra load, created by the artifi ial gravity (Figure 12).

To achieve efficien space utilisation, it was advised to develop a cylinder-inside-a-cylinder structure for ECH. This structure enables the use of cylinder as a support in the rotational motion for artificial gravity creation

External shell has diameter of a 500 m and internal pressure of 0.7 atm. Artificial gravity is 0.7*g*, which equates to 0.16 rad/s of rotational speed. Cylinder shell walls are 62.9 mm thick. Calculation results are illustrated in Figure 13.

Internal cylinder has diameter of 300 m and internal pressure of 1 atm. Pressure difference applied on the cylinder is 0.3 atm. Artificial gravity is 0.7*g*, which is created by applying the rotational speed of 0.21 rad/s. Cylinder's walls are 33.5 mm thick. Simulation results are illustrated in Figure 14.

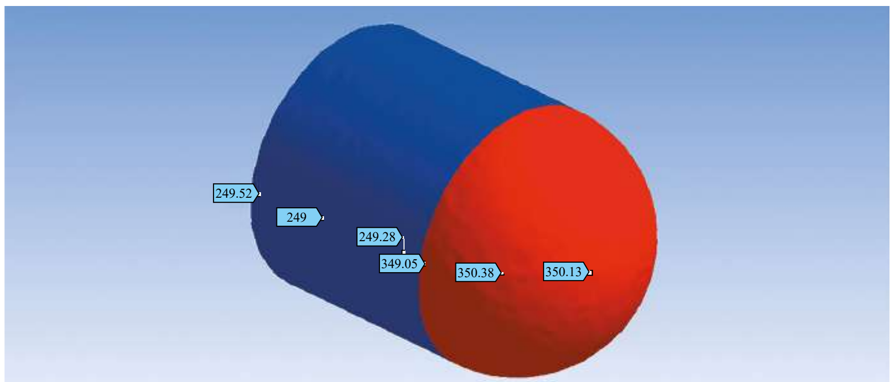

Figure 11 – Stage 1. Stress distribution in the shells
with 2.4286 ratio between their thicknesses

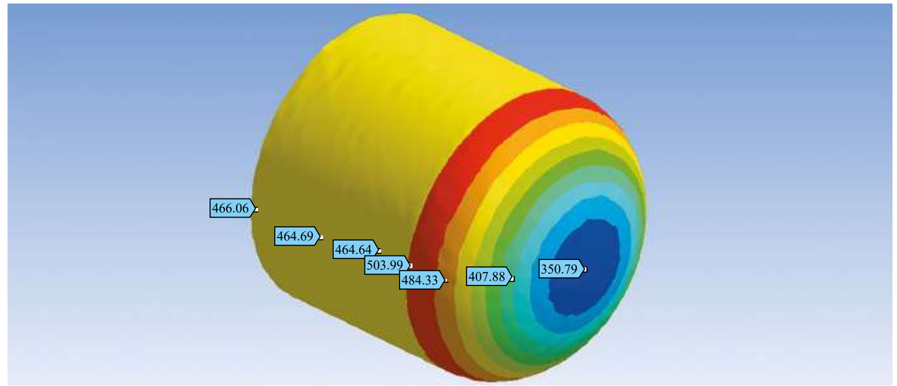

Figure 12 – Stage 2. Stress distribution in the shells with 2.4286 ratio between their thicknesses

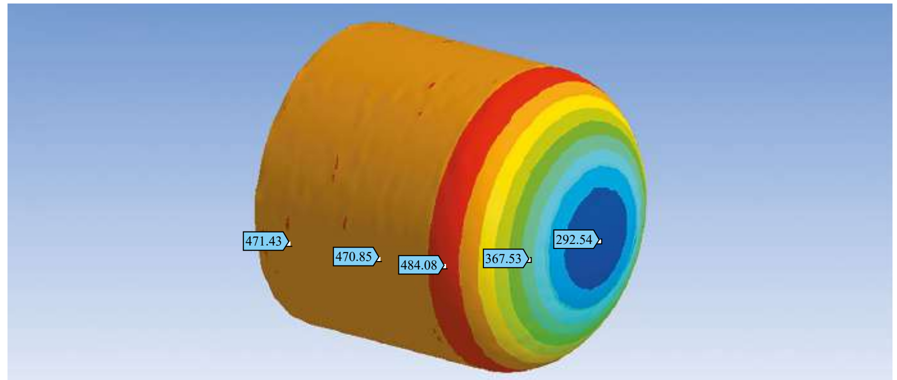

Figure 13 – Stage 2. Stress distribution in the 500-metre-diameter shell with internal pressure of 0.7 atm

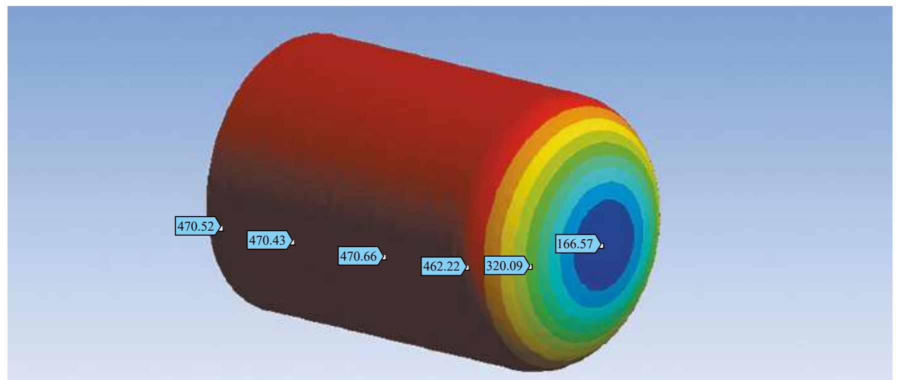

Figure 14 – Stage 2. Stress distribution in the 300-metre-diameter shell
at 1 atm of internal pressure and 0.3 atm of pressure differenc

C. Performance of ECH Shells in Collision with High-Speed Objects

Simulation results of the collision studies between the ECH and high-speed cosmic objects showed protection efficienc of the developed protection solution. Study results demonstrated absence of the full penetration in collisions with a metal ball with a diameter of 200 mm having mass of 32.8 kg and moving with velocities of 10 km/s (Figure 15) and 20 km/s (Figure 16). The soil layer experienced a creation of the crater with the depth of 3 m.

However, collisions with the larger objects or with the objects, having larger velocities, may lead to the full penetration through the shell. Additional collision

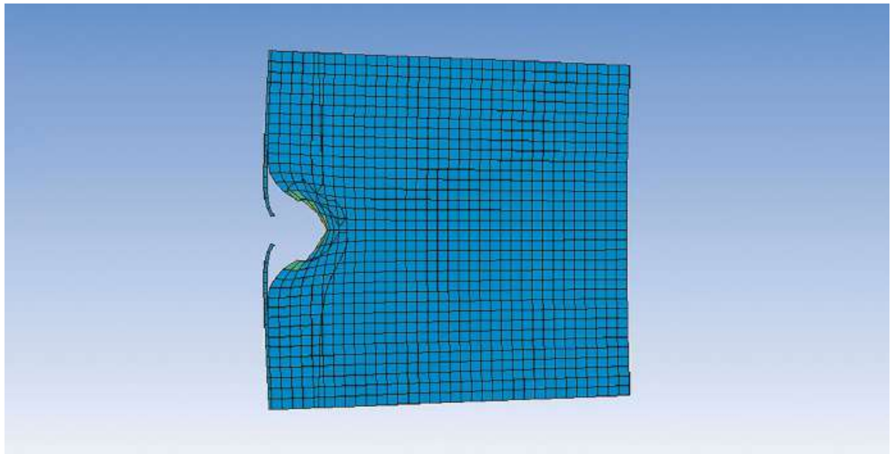

Figure 15 – Collision results with a 200-mm-radius object at a speed of 10 km/s

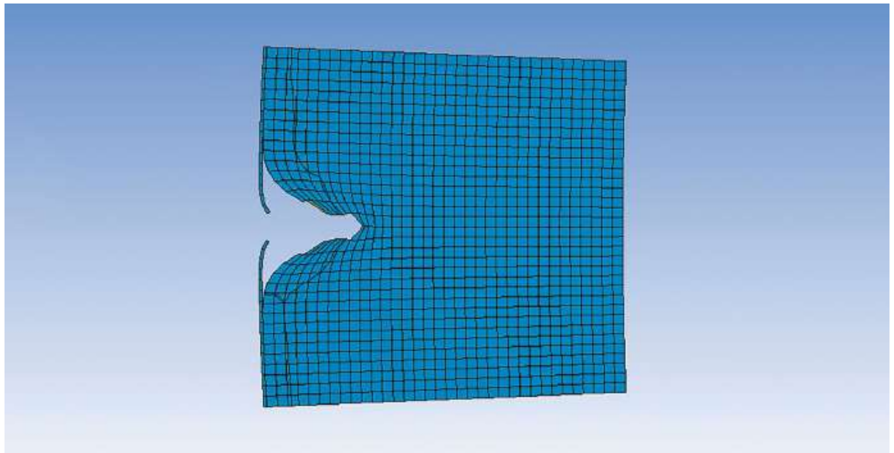

Figure 16 – Collision results with a 200-mm-radius object at a speed of 20 km/s

studies included metal ball having diameter of 400 mm, mass of 263 kg and moving with velocities of 10 km/s (Figure 17) and 20 km/s (Figure 18). Simulation results demonstrated severe damage occurring at 0.15 s upon contact between a high-speed object and external shell.

This damage leads to the depressurisation of the shell, which forces the air to leave ECH through the gaps between the shells. However, it does not adversely affect life-supporting systems of ECH, as people would live inside an internal cylinder, while inside an external cylinder a closed vegetation ecosystem (gardens, meadows, forests) will be created and which could sustain drastic drop in the air pressure.

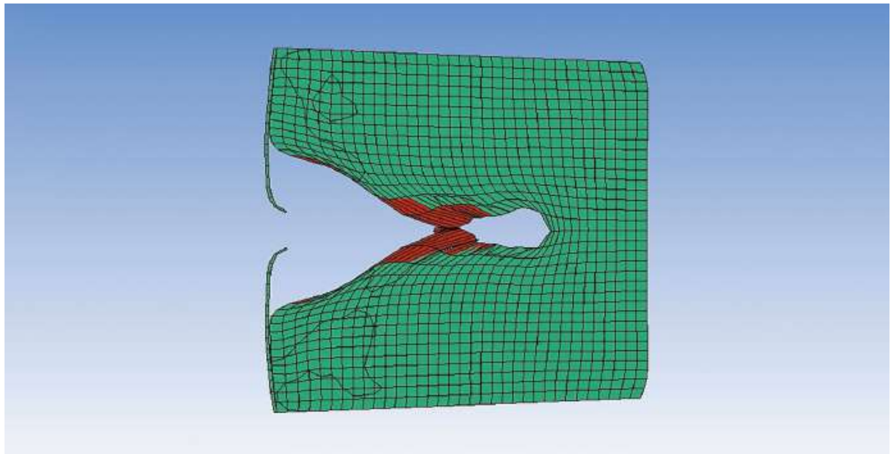

Figure 17 – Collision results with a 400-mm-radius object at a speed of 10 km/s

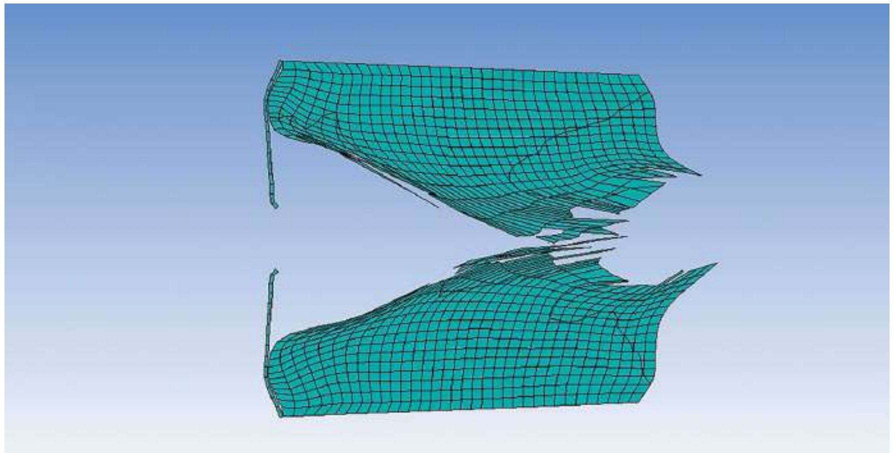

Figure 18 – Collision results with a 400-mm-radius object at a speed of 20 km/s

13.5 Conclusions and Future Work

This paper compared two functional shapes of ECH. Simulation results demonstrated that thin-walled toroidal structure with a layer with the soil cannot be developed without installation of the extra bearing structures. Additionally, membrane structural theory did not work under the given conditions.

Simulation studies of the cylindrical design pattern demonstrated the need to minimise joined deformation in the intersections of cylindrical and spherical sections of ECH. This task is achievable with use ratio of walls' thicknesses, which depends on the applied materials. Further study should be done with non-homogeneous composite materials.

Designed protection shell, with the soil thickness of 10 m, demonstrated its structural integrity in the collision with a ball-shaped objects up to 200 mm in size having mass up to 50 kg, moving with a velocity up to 20 km/s, as an example of the collision with the metal meteorites (not by stone or icy ones). Generally, space debris has a more complex shape and greater porosity (it is not a dense ball), so it is reasonable to assume that protection will be effective against space objects up to 100 kg in mass. However, in any case of collision, a shell material is damaged. It would lead to a loss of useful resources and tragic loss of space station citizens.

Study results demonstrated high importance of the installation and development of the extra protection, like Whipple shield, to minimise shell's damage [5, 6]. It is also highly advisable to study designs of the detection and destruction systems for the objects, which diameters exceed 300 mm. These systems will allow to avoid any collisions between ECH and large objects.

It is highly important to study the composition of the soil to achieved density reduction (for load reduction on the shell), as well as design ability for self-healing of the shell holes upon hitting. It is also necessary to develop an isolated enclosed ecosystem zone in between shells and inside the internal shell, so that even full penetration through the external shell would not lead to a tragic accident with the residents of ECH. Moreover, when planting vegetation inside the internal shell, it is important to consider their ability to decelerate, via their root system, tree trunks and crowns, falling meteorites that fully penetrate through the external shell.

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14

Principles of Building a Healthy Environment for Human Life, Work, Development, and Recreation in EcoCosmoHouse

Being born, a person initially has everything he needs for his life. These conditions have been created evolutionarily on our planet, including specific gaseous composition of air, appropriate temperature range, availability of water, soil, food, diversity of living organisms, etc. A person is born in a family and he or she immediately becomes a member of the "social unit". It creates necessary environment to meet child's vitally important social needs. The needs for security, belonging and love are addressed. In modern society, the first twenty years of each individual's life are so clearly arranged that the satisfaction of such needs as development, respect, and self-realisation depend not so much on the efforts undertaken, but on the perception of the surrounding world and occurred events. For self-actualization and unlocking of internal potential, the whole world is open to a person, in which he or she is free to choose the forms of realisation of these needs [1].

This research considers a number of problems. What happens if we try to create an isolated living space? What should it include? What should it consist of, in order not to stop, but on the contrary, to accelerate people's development therein? These principles create a foundation of EcoCosmoHouse (ECH) [2].

In order to create a healthy environment for life, work, and recreation, it is necessary to defi e a list of needs that have to be taken into account in the newly formed space and society. It can be done by analysing a psychological portrait of a potential

test resident of ECH, with regard to his or her "layer" of needs and opportunities for their development and growth. At the same time, it is important to:

- identify the lowest acceptable threshold of a personal development necessary for participation in the project as a test resident;
- consider the emerging community of test residents as a harmonious entity in which people complement each other in various aspects (professional, physical, emotional, etc.);
- keep in mind the need for self-development and personal growth as one of the basic needs of any human being;
- take into account impact of the enclosed conditions on people's lives, based on their isolation from the usual environmental elements, such as sky, view of the horizon, the possibility to change the environment, etc.;
- take into account the conditions of a limited social circle and the impossibility of changing it for a certain period of time;
- take into account the possibility of emergency and unforeseen circumstances;
- consider other factors influencing changes in behaviour, health, and personal perception within a closed environment.

In order to obtain additional information on the possible criteria for selecting the residents of ECH, we have studied the current requirements for astronauts during the selection to the "Yu.A. Gagarin Research & Test Cosmonaut Training Center" [3]. The main selection criteria are age, medical indicators, anthropometric data (strict selection by height, weight, and other parameters), physical training (endurance, strength, agility), higher education in engineering or fl ght specialties with work experience of minimum three years, ability to study and perform work as an operator, knowledge of foreign languages and the basics of cosmonautics, absence of criminal convictions and criminal prosecutions. Besides, experienced psychologists carry out special psychological studies and observations. At the same time, individual (emotional, cognitive, volitional), social (degree of professional self-determination, interpersonal skills, aspirations, and personality inclinations), and psychological characteristics are also analysed.

For a better understanding of these issues, the social and psychological problems that have occurred in other experiments in closed ecosystems, such as BIOS-3 [4] and Biosphere-2 [5], have been analysed. The general state of people in those projects was influenced by both external factors, such as lack of oxygen, food, hard daily work, and interpersonal relations. External factors led to the deterioration of health and, as a consequence, to the suppressed moral state. Experienced difficulties divided participants into groups with opposing views. This process caused most conflicts These disagreements, in turn, triggered a further deterioration in already negatively affected health state

In the future, EcoCosmoHouses will be built on orbit. Before that happens, set of experiments, simulating isolated biospheric conditions, should be performed on the Earth.

From the abovementioned it can be determined that criteria for selecting test residents for the initial experiments within EcoCosmoHouse on Planet Earth (ECH-Earth) have to include person's physical characteristics (health, physical training), presence of necessary knowledge (general, professional, and about research subjects), and certain psychological qualities (personal and social). Additionally, the author of this research work suggests "team matrix" selection approach to be used. It is a system where the necessary characteristics of a single team are distributed to its members, creating avatars of the future specialists that form a team, which is fully functional to achieve specific purposes.

Several theories of human needs were analysed to identify a view of the conditions, which should be arranged within ECH. Examples may include the pyramid of A. Maslow [1] and the spiral dynamics of K. Graves, D. Beck, and K. Kovan [6]. Both systems are presented in a form of hierarchies of needs. They reflect the development of human consciousness, as well as the entire society. The bottom level of the hierarchies is the physical level, which includes only a range of personal needs. The top level is the level of full potential with a global vision and an integrated approach [7]. Moreover, being at higher levels of development does not deny the need to meet the needs of previous levels, but, on the contrary, emphasizes their implementation as a basis for further growth. It can be concluded, that it is necessary to satisfy the full range of needs to make a person's life worth living in an enclosed environment: from basic physiological needs to full self-actualization.

The fi st priority should be given to the modelling of the conditions to satisfy the basic needs, as the foundation of the entire experiment. And it is important to note that this foundation implies a harmonious combination of all physical components of the biosphere not only for humans, but also for animals, plants, and other living organisms. These components include: maintenance of climatic parameters, compositions of air, soil, water, availability of necessary quantity of a foodstuff containing the necessary vitamins, micro- and macroelements, a variety of plants, animals, and other elements of nature.

If we investigate the living conditions on Earth as the only analogue of favourable conditions for *Homo sapiens*, it becomes obvious that the basis of these conditions is nature. Consequently, in a closed artificial biosphere it is necessary to form the most natural conditions for human habitation in combination with the necessary technical achievements of civilization.

Permaculture is the modern advanced natural approach in space planning, landscaping, and farming [8]. The advantage of this approach is the use of natural rather than nature-like technologies. Creators and followers of this direction are the nature observers. They assign the same value to the care of the Earth, with all its components of living and non-living nature, and care of people. The main principles of permaculture are harmonious interaction of all elements of the environment, where each of them has several functions and provides existence to other elements, cre- ation of the biological diversity, copying of natural schemes and algorithms, effe -tive energy planning, and use of renewable and biological resources. Designing natural ECH areas in accordance with the principles of permaculture will allow creation of the most natural relief and landscape features, natural interconnections of ecosystems, their effective interaction, and human life as part of th bioworld.

Nevertheless, providing all the necessary physical conditions for a person's life is not enough for people to be healthy. Besides physical parameters, there are also psychological ones. In a context of survival, they can be reduced to the concept of stress tolerance. If we take into account the results of psychological researches, we will see that 20 % of people in crisis situations need the help of professionals [9]. People of this segment are the subject of interest to specialist in Western medicine, whose work is aimed at identification and treatment of the already occurred diseases. In health psychology, this focus on disease management is called Pathogenic Paradigm. However, in the opinion of the author, while creating a new living environment, it is necessary to consider initially the options for providing conditions that would not only treat diseases, but also reduce the possibility of their onset. This approach, named by A. Antonovsky, professor of medical sociology, is known as salutogenic (salutogenesis comes from the Latin *salutis* which means health and the Greek *genesis* which means origin), which is literally oriented towards the study of the origin of health [10].

The subject of Antonovsky's research was the psychological characteristics of people who experienced stress to various degrees, such as those who survived concentration camps, and not only retained their health, but also remained happy. The conclusion of these studies is that the impact of stress on people is determined by their individual ways of responding to the situation. The most stress resistant people are the ones who perceive the world in meaningful and manageable ways. "Sense of coherence", which is the feeling of connection, coherence, is typical to such people. It allows them to assess objectively emerging threats and perceive them as challenges that bring new opportunities, as well as to assess their own resources required to solve the problems [11]. That is exactly the attitude that ensures good health.

How can one use the principles of salutogenesis in design of the living environment? The need to create understandable, easy to perceive, comfortable, safe and manageable conditions, in other words, a sustainable and healthy environment, becomes obvious. It is also important to focus not only on risk factors and disease treatment, but also on factors that preserve and improve health. This approach can be achieved only with the systematic introduction of the question: "What else can be improved or envisaged to maintain and improve health?"

Since there are many lifestyle-related diseases in the world today (obesity, diabetes, respiratory diseases, cardiovascular diseases, etc.), it is important to focus on planning and architectural solutions. They should encourage a healthy lifestyle, which may include picturesque walking areas, convenient sports grounds, aesthetic inclusion of architecture into natural environment, ergonomics, suitable illumination, and absence of destructive oppressive elements (noise, "poisonous" colours, tangible vibrations, and unpleasant smells). Availability of healthy and tasty food and their proper preparation, absence of knowingly harmful products (containing large amounts of sugar, preservatives, stabilizers, and other harmful chemicals) are similarly important for human health. It is important to design professionally space with inclusion

of zones for social activities (communication, work, education, interaction, and creativity) and private rest areas, which are necessary for psychological well-being [12].

Several research works show equal importance of physical and psychological comforts and their influence on the psychological states and, subsequently, states of other people and relative sphere of life. For example, K. Porat from the Georgetown University studied the impact of rudeness in a workplace on the fin ncial results of the company [13]. Many people admit that rude words, voice increase, impudence, and disrespectful remarks, especially from managers, have a negative impact on the emotional background of any team, but few people realise that such behaviour leads to increased expenses. The survey revealed that 47 % of employees consciously work less or less intensively, with less creativity, 80 % feel offended and spend time to reflect on their conditions instead of working, 78 % admit that they are disappointed in the company, and 25 % admit that they take out their irritation on clients and other employees. Cisco, an American multinational communication company with a reputation for being an exemplary employer with a friendly and polite team, became interested in the survey findings. The company estimated only three types of expenses and made a detailed estimate, according to which company loses 12 mln USD per year due to the violation of courtesy standards.

Any rudeness act as a spark that ignites the fuse of the psychological state in a certain group of people and beyond them, as communication continues in families and other groups. And if we are talking about an enclosed environment with a limited communication connection, as in the case with ECH, the creation of a friendly atmosphere and the selection of participants with the appropriate character features are among the factors that determine the success of the experiment, and, in the future, success of the entire space exploration process.

Thus, having analysed physical and psychological needs of a person, the first reference points and principles of a healthy environment formation in a closed artificia biosphere have been identified. However, if these needs are to be met in the long term, their subsequent development must be considered. Person is always moving forward, based on his or her fundamental needs. It is impossible to stay on same level forever and there are only two directions: either development or degradation. ECH should not become the place, which will reduce the potential of *Homo sapiens*. The need for continuous development and self-actualization of each individual is comparable to the need in realising releasing mankind's potential to go further, into space, beyond existing borders. This is just as obvious as the next stage of the technocratic development of civilization, which is space industrialization and removal of all harmful industries outside the boundaries of the biosphere [2].

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15

Organisation of the Internal Space of Touristic Cylindrical EcoCosmoHouse

15.1 Internal Design of Touristic Cylindrical EcoCosmoHouse

The topic of a space tourism has already been discussed for decades. Its significance is determined by human desire for knowledge, as much as the opportunity to experience living conditions different from the terrestrial ones. At the moment this industry only begins its deployment, as short-term flights as well as programmes for long-term orbiting stay of the space tourists are under development. Modern solutions for transporting people and cargo into space are expensive, ineffective, and harmful to the environment [1]. The concepts of space hotels and colonies proposed earlier are distinguished by their large volumes and weight as much as by the fragmentation of planning zones, with the difficultie of establishing connection between them.

For now, the only platform for long-term stay in space is the International Space Station (ISS), which was constructed only to support work of the astronauts, and is inappropriate to be considered as a residence for the large number of people. This raises the issue of need in stations and space hotels with the ability to accommodate a regular flow of a large number of guests and independently supply visitors with the necessary resources. As a viable solution to be analysed the research proposes a construction option of the EcoCosmoHouse (ECH) project, which is included into the SpaceWay subprogramme of the non-rocket space exploration [2].

An integrated approach to the space settlements design developed over the last century covers many aspects, and the further research makes these concepts accomplishable.

However, some areas need further development and redefining. The ECH design considers the feasibility of shell weight reduction without losing its strength characteristics. Carbon fiber is considered as the main structural material, which allows to avoid the excessive mass of the protective layer.

The cylindrical form of ECH experiences only tensile forces, however it is not subjected to the bending deformations under the influence of artificial gravity. The compact arrangement of two enclosed ecosystem volumes "cylinder in cylinder" minimizes the cost of materials, as well as engineering systems and services. At the same time, relatively small volume of ECH provides an increase of the useful area including agricultural, residential, and recreational areas, in contrast to other currently suggested designs. The planning distribution of the functional zones within the cylinders makes it possible to separate the agricultural zone from the residential and recreational areas. This solution will not only provide a significant reduction of a noise and odours produced by livestock complexes, but also preserve the integral structure of the biosphere with residential and agricultural zones, distribute the loads of engineering systems, and also ensure higher safety for the space settlement inhabitants.

Unlike the other developed concepts, the absence of the opening sections in ECH preserves the continuity of load-bearing and protective shells (antimeteorite and antiradiation), increases strength characteristics, as well as clears the outer shell's useful surface area, thus enabling to place industrial zones and a large number of solar panels on it.

A. Review of Existing Proposals and Ideas for Space Colonies and Hotels

Bernal Sphere

One of the first space settlement prototypes was presented by British physicist and sociologist J. Bernal. In his scientific essay "The World, the Flesh and the Devil: An Enquiry into the Future of the Three Enemies of the Rational Soul", published in 1929, he described a spherical shell, 16 km in diameter, which rotation is provided by the equatorial gravity [3]. Its structure is only partly composed of terrestrial materials while the main structural materials are taken from asteroids, Saturn rings, or other planetary detritus. This solution is expensive and requires the invention of special equipment for the extraction and processing of such construction materials. The spherical shape is as manoeuvrable as the cylindrical one, however, cylinder's useful inner surface area is larger. The sphere is equipped with lots of engineering systems and with an observatory. The main industry of the solution is an affordable energy production generated by the space solar stations and transmitted by microwaves to Earth. This solution does not solve the issues of the placement of the industrial zones.

The living area located within the interior space that can accommodate up to 20,000–30,000 people. The main life processes take place in the free area located in the centre of the sphere, and furthermore, there are isolated cells with thin soundproof partitions provided for concentrated work. The population of the sphere is not fixed, as there would be a constant exchange between its settlement and Earth [3].

Island I

Island I (One), or a modified Bernal Sphere, was proposed by the American physicist G. O'Neill in a series of researches established between 1975 and 1976 at the Stanford University to explore future space colonies projects [4]. The diameter of the sphere in the new proposal is 500 m with the rotation speed of 1.9 rpm.

The inner area contains a living zone designed to accommodate about a thousand people, and this number is significantly lower than ECH can provide with its relatively similar dimensions.

The agricultural rings are located on both sides of the living area of Island I facility common axis. Their location results from the crops low radiation susceptibility. These rings consist of several storeys: agricultural crops have closest location to the Island I axis, while the lower storeys with the higher artificial gravity are given over the livestock farming. Thus, the process of growing food is separated from the inhabited areas, which makes it difficult to deliver products, as well as look after plants in a potentially dangerous area with high radiation.

Large flat panels at the ends of the Island I facility supply the system with a solar energy. Factories and space docks are located at the opposite ends of a long pipe in a gravity-free zone, which makes this solution resource-intensive due to the lack of compactness.

O'Neill Cylinder

"Space Colonies and Energy Supply to the Earth" is a scientific paper published in 1975, in which G. O'Neill described the Island III (Three) space settlement [5]. According to O'Neill's hypothesizes, the most efficient form is two communicating cylinders that provide rather low manoeuvrability of the Island III. These cylinders can be up to 25 km in length and have a diameter up to 6 km, what leads to the high construction costs.

The circumference of the cylinders is divided into alternate strips of land ("valleys") and window-like openings ("solars"). This structure makes them vulnerable to the aggressive external space environment and makes it difficult to access from one land zone to another. Valleys on the inner surface, like terrestrial landscapes, include living spaces, parks, forests with lakes, rivers, grass, trees, animals, and birds.

Agricultural areas are separated from residential zones by cylinders located 32 km from the main area. Each cylinder has its climate adapted for the cultivation of certain crops. Gravity, atmosphere and insolation conditions of the majority of the agricultural cylinders are similar to the terrestrial ones, while the remaining cylinders are dedicated for experimental studies. The plants growth phases alternate evenly, thereby ensuring the constant harvest in several cylinders. Such placement of the agricultural areas makes it difficult to organise efficient plants cultivation and products delivery.

Solar power plants, which consist of the parabolic mirrors, boiler tubes and electric generators, will provide the population with enough energy. Additional power plants near the agricultural ring may be switched on once the population density increases [6].

Stanford Torus

This project was proposed by the Stanford University students in 1975. It is a pipe 130 m in diameter which is bent into a torus about 1,800 m in diameter [7]. In contrast to the capsule form of ECH, Stanford Torus is susceptible to deformations of the main body under the force of artifi ial gravity. Six "spokes" with 15 m cross-section diameter designed to sustain excessive deformations connect the torus to the central axis and accommodate elevators, power cables and engineering networks.

Glass windows mounted on the aluminium ribs cover 1/3 of the torus surface and allow sunlight to reach agricultural and residential areas, however it makes the significant part of the surface unusable

The residential area of 43 ha can accommodate up to 10,000 people, which is a very high indicator of density, since only 43 m^2 of internal surface is allocated per inhabitant.

The space inside the torus body is organised in accordance with the need for pedestrian accessibility of the transport "spokes", acoustic isolation from noisy commerce and services, fire safet , and weight distribution around the torus circumference.

Three residential areas in the torus are separated by the isolated agricultural zones. This arrangement allows to increase temperatures, carbon dioxide, humidity, and lighting levels in controlled areas to accelerate plant growth, as well as protect plants and animals from various diseases. At the same time life processes discretely take place in the compartments which makes the service between them diffi ult, and the plant care becomes complicated because of the unsafe conditions for the inhabitants.

The territory provides for possibilities of new settlements and solar power plants construction, as well as for satellite repairs and other types of maintenance. Absolute vacuum allows to organise production of unique materials, such as foam steel and monocrystals.

Kalpana One Project

In 2006 professors at the American Institute of Aeronautics and Astronautics proposed the Kalpana One project as a new vision of the 1970s concepts (such as Island I and O'Neill Cylinder). The structure is a cylinder with a 250 m radius, 325 m length, and population of 3,000 people [8]. This radius is the minimum to ensure 2 rpm rotation.

Kalpana One's rotational axis is aligned with the "north – south" axis of the Solar System, which provides continuous insolation through the transparent part of the body. This solution allows an effective use of the low-gravity zones

The settlement is located within the inner cylinder while industry, warehouses and agricultural zones are placed in the outer areas with lower gravitational forces. Elevators and ramps are used as connection passages and cargo delivery channels between the cylinders. Thus, the connection between agricultural and residential areas is difficult, which minimizes human participation in a cultivat n process.

The total surface area of the inner cylinder is 510,000 m^2, which provides 170 m^2 for each of the 3,000 residents. This density allows to organise long-term stays in Kalpana One. Residential areas are combined with recreational ones, as well as spaces for sports, dancing, active games and swimming pools, thus creating an optimal life balance.

The required agricultural area for 3,000 people is 150,000 m^2. This area is located in the inner cylinder with a 140 m radius in a low-gravity environment. The whole area is divided into several compartments that can operate under controlled atmosphere, temperature, and lighting conditions for fast and efficient growth of the crops [8].

Von Braun Station

The goal of the project is to form a space construction industry that can accelerate Solar System colonization. The Gateway Foundation start-up plans to put a space hotel into operation by 2025 [9]. The space hotel is to be built in a shape of a wheel with a 190 m diameter in order to create an artificial gravity due to rotation, thus making the whole construction subjected to the deformations in the same way as Stanford Torus. The station is designed for human adaptation to the microgravity effects by simulation Moon's reduced gravity.

The station will be able to accommodate 350–450 people, including 100 members of the crew, thus making construction and operation costs very high per inhabitant.

The project includes 24 modules up to 500 m^2 each used for different purposes, such as public zones (bars, restaurants, recreation areas), hotels, and private residences as well as research modules. Sports activities provided in the zero gravity area are basketball, low gravity trampoline jumping and climbing.

Hotel's visitors will not have to deal with the microgravity toilets and showers, like astronauts on the ISS do. All drinking water will be delivered directly from Earth and recycled for technical purposes. This solution excludes autonomy of the station due to the constant need of drinking water delivery, in contrast to ECH where aquatic ecosystems (containing sea and fresh water) and water purification systems designed to supply water in a natural way.

International Space Station

Currently, the ISS is the only option for space tourism on-orbit. The first station element was launched on November 20, 1998 [10]. Only eight space tourists have visited the ISS so far, which indicates the station's low capacity, due to the prohibitively expensive cost of the trip, need for the long preparations, and the small capacity of the ISS facilities. The station dimensions are 108 × 74 m, the volume is about 1,250 m^3, however it cannot accommodate many people unlike ECH. The facility was built by step-by-step attachment of the blocks and modules.

Now the ISS includes 15 modules. These modules are designed for housing, laboratories, greenhouses, training, Earth observation, and work in the outer space, as well as for the fuel storage, docking, and spacewalks. There is no garbage processing system on the ISS, the amount of water is limited due to the difficult of delivering cargo from Earth. Electricity is supplied by the solar panels located on the outer surface of the station. The station doesn't provide sufficien protection against radiation unlike ECH, where the main place of human habitation (the inner living cylinder) is protected by an outer cylinder that includes the ground, technical and industrial layers.

B. Functional Zoning of Internal Space of Cylindrical ECH. Scenarios of the Settlements and Living Conditions

Designed by the engineer A. Unitsky, the geometry of the ECH's shell is defined by the comfortable gravity for the people, bionic form, and hierarchy of spaces required for various functions and effective use of the materials. The space settlement is a system of two cylinders with reciprocal counter rotation around a common axis. The diameter of the outer cylinder is 500 m with a length of 500 m, the inner one has diameter of 300 m with a length of 500 m. The total length of the structure is 1 km (Figure 1).

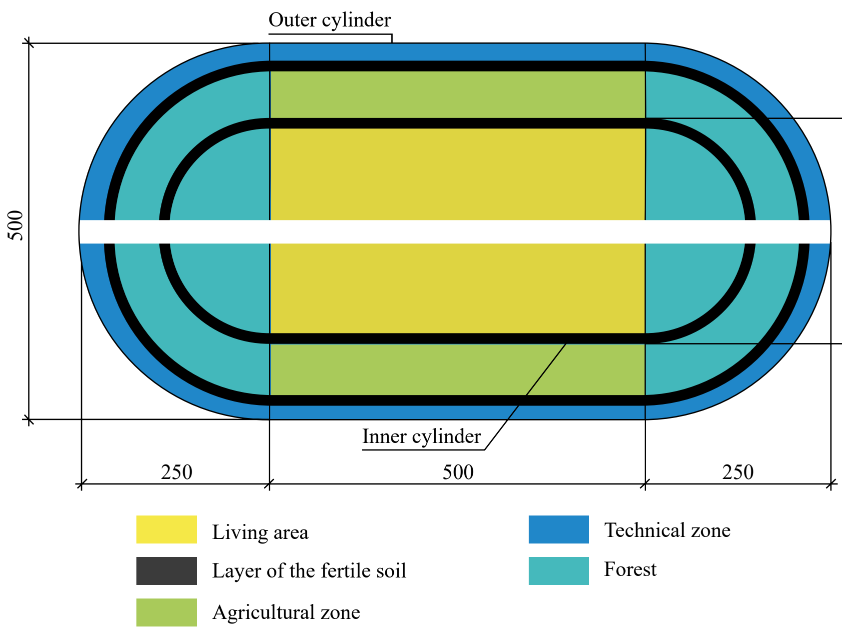


Figure 1 – The internal organisation of ECH

The inner space of the cylindrical ECH is formed by two enclosed shells that are gradually distanced from its central tubular axis, which provides connection with the outer space and communication between the living and agricultural zones of the space settlement.

The distribution of functional zones is based to the pedestrian accessibility, logistics of goods and products delivery, optimisation of engineering systems, efficien land use, human-scaled environment, and optimal density of residential buildings.

A multistorey technical zone with a height of about 10 m is located at the outer surface of a large cylinder. The presence of this space and its volume are determined by the need of placement of the tanks with drinking and industrial water, warehouses for storing food and equipment, as well as compartments with multi-level autonomous greenhouses for growing an additional volume of products and other elements.

The rooms for plant cultivation are equipped with artificial lighting and robots that use a printer method for cultivation [11]. This technology allows planting, cultivation, and harvesting of the crops without human intervention, while growing conditions in greenhouses correspond to the natural climatic conditions genetically recorded in the DNA of plants over billions of years of evolution on Earth. Environmental parameters that do not affect the quality of agricultural products, but increase the productivity of their production – such as humidity, temperature, carbon dioxide levels, lighting, gravity level, etc. – will be optimised and can be regulated at diffe - ent periods of plants growing.

ECH provides for the possibility of using engineering systems in addition to the main natural processes of water and air purification, waste disposal, carbon dioxide filtration, etc. Delivery from warehouses and reservoirs is organised autonomously. The system of sectors and locks ensures safety and autonomous functioning of all engineering systems of the technical zones, in order to prevent interruptions in case of the possible collisions with meteorites. In addition, ECH will be surrounded by a fine-me h net at a distance of several tens of metres. The net will create a space with a vacuum and zero gravity conditions, which are necessary for several space industries with corresponding technological equipment. In addition, it will become the first protective layer – as a result, meteorite that is larger than the mesh cell will be partially crushed and its fragments will fly further, encountering technological equipment that will take the second blow. Therefore, only the weakened remains of the meteorite will reach the inner shell of ECH, which ensures its tightness.

Above the technical zone, there is a multi-metre layer of fertile soil, which will become not only the main mechanical protection against meteorite and radiation, but also "green lungs" of ECH, and the basis for recreational and agricultural zones. Soil biogeocenose with thousands of species of microorganisms will be able to support the vital activity of flora and fauna in the enclosed ecosystem of a space settlement [2]. The integration of nature-like engineering communications with the natural soil layer will provide constant irrigation and full plant nutrition (without chemical fertilisers and pesticides).

The multi-metre layer of the "space" soil, which can absorb the impact of an up to 100 kg meteorite, contains a mineral and fertile component in the form of natural humus in the amount of 10 %, which makes is similar to the most fertile terrestrial soil – the chernozem. In order to reduce the weight, the mineral part is made out of foamed granules of earth minerals, the fractional composition of which does not interfere with the growth of the plants root system, and, at the same time, has the necessary collision and radiation protection properties.

The inner space of the space settlement is represented by the changing plain, foothill, and mountain (at the ends of the cylinders) landscapes, which creates a natural visual environment (Figure 2). This shell contains an area for growing various crops, territories for livestock breeding, sports grounds, walkways, and green areas for planting food for the residents of ECH. The system of ponds and streams is evenly distributed, forming an irrigation network and a system of stage-by-stage water treatment with mineral and organic loadings. Reservoirs are classified according to

- purpose (either recreational with a beach area or for breeding fish, aquatic plants, molluscs, and other food products);
- composition of water (either salty or fresh water ponds, based on the chemical compositions, each of the systems having their aquatic ecosystems similar to those on Earth).

There are also plants that are grown around the water bodies to strengthen the coastal soil.

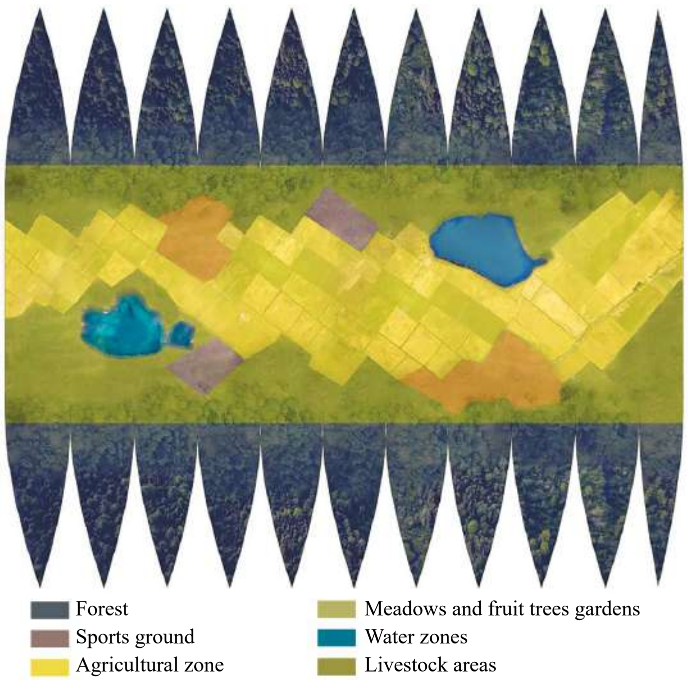


Figure 2 – Option of an inner space zoning of the ECH outer cylinder (flat view

Livestock complexes are surrounded by hedges of trees, shrubs, and climbing plants which are about 10 m high. It is also necessary to ensure the movement of air (wind) away from places where people often stay. Wind is also important for pollination of plants and strengthening (training) their stems and trunks. Air movement, light wind, and air exchange in the gap between the cylinders are easy to organise, since they rotate in opposite directions with a relative speed exceeding 10 m/s. For this purpose, the outer surface of the inner cylinder can be equipped with special blades able to adjust wind performance.

Fields for harvesting of vegetables, medical herbs, industrial crops and orchards are located near livestock farms. Families of bees and bumblebees (for plants pollination) should be placed on each agricultural area. Plant hedges with a height of about 10 m will be planted around the recreation areas to prevent the penetration of pollen and pollinating insects.

For visual and psychological comfort, above the green zone there is a 100-metre air gap which is bounded by the inner cylinder that imitates the sky. The height of the sky section should be several tens of metres more than the tallest trees.

Life in the orbit presents many challenges for humans: different health threats, lengthy adaptation processes, atmospheric composition which is different from the terrestrial one [12]. To maintain physical and psychological comfort, as well as for additional health improvement, ECH includes locations for training and active games, walkways, eco trails, climatotherapy zones, and areas for swimming in reservoirs (Table).

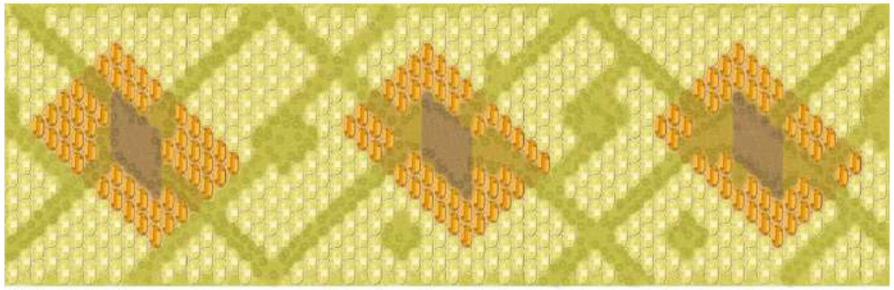
Table – Functional zones of the inner space of the outer cylinder of EcoCosmoHouse

Zone name	Number, %
Forests	30
Fields	30
Meadows with animal breeding areas	20
Water zones	15
Sports grounds	5

Hotels and living areas are placed on the inner cylinder of ECH on a multi-metre layer of "space" soil, which are carefully integrated in the ecosystem. A separated residential area provides additional safety for tourists and residents of the complex. To create comfortable living conditions, it is necessary to determine the optimal density and population size. Various options for building and residence density are described below.

High-Density Development for Short-Term Tourist Expeditions

High-density development allows to accommodate about 10,000 tourists at the ECH size described above. This solution will be suitable for short-term (up to several weeks) expeditions (Figure 3). Under the conditions of a given density in mid-rise buildings, the quality of life is improved due to the organisation of the hierarchy of spaces, from public to private [13].



Public area Mid-rise living area Low-rise living area

Figure 3 – Scheme of a fragment of high-density ECH living area of inner cylinder (variant)

This settlement's system allows to organise a high capacity of ECH. Also, the positive side is the possibility of a steady flow and experience exchange between a large number of specialists: scientists (research, lectures, seminars, master classes), farmers (caring for plants and animals), staff (tourist animation activities, training in various directions), and others. Most of the services will be automated and tuned in accordance with the planned use scenarios to ensure the smooth functioning of ECH. The delivery from warehouses, planting and caring for plants, cleaning, cooking should be highly automated.

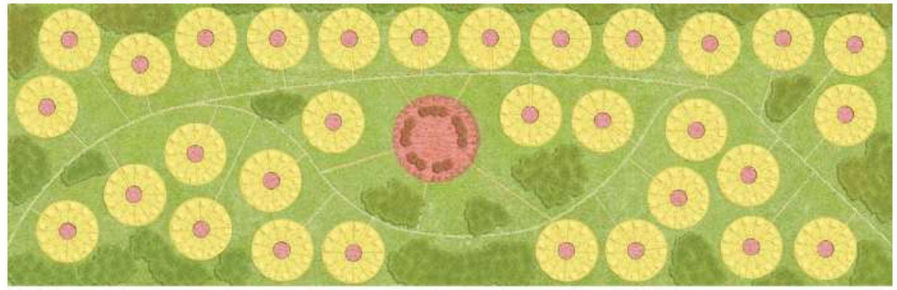
Negative factors of the high-density construction are: higher consumption of supplies, significant load on waste processing systems, reduced control over the created closed ecosystem due to the constant export and import of substances from the outside, high noise level, short adaptation period, lack of a sense of ownership and, as a result, consumer's attitude to housing facilities, reduction of secluded spaces, and availability of private recreation only for VIP tourists.

The studies of N. Gurovsky and A. Egorov identified that during the fligh and in the post-fl ght period, at least one third of the cosmonauts experience symptoms similar to motion sickness during the first 3–6 days after the end of the fligh [14]. If the duration of stay in ECH is limited to a few weeks, the process of adaptation would take a significant part of the trip. Increased stay duration in a high-density environment can lead to the psychological discomfort of tourists.

Low-Density Low-Rise Development for Long-Term Stay

Low-density development will allow to disperse residential development and build a chamber-based settlement with individual estates, that will create optimal conditions for long, comfortable, and safe staying in space. Such settlement arrangement can accommodate about 2,500 people at the rate of one house with a roof garden

and area of 100 m^2 as well as a personal household plot of approximately the same area for each inhabitant (Figure 4). If the rate is a house per family, the number of ECH inhabitants can be increased up to no less than 5,000 people.



Public area Low-rise living area Green area

Figure 4 – A fragment of a low-density solution of the ECH living area

Positive aspects of low-density construction are: long-term trips compensate the adaptation period and increase the adaptability of the space tourists to the ECH environment; individual estates create a sense of ownership, providing constant maintenance of the territory and an increased level of the living comfort; a reduced consumption of provision leads to the decreased number of greenhouses in the technical zone, lower wear and tear of territories and engineering systems, and a moderate load on waste processing systems.

The downsides of this construction are lower ECH capacity, higher cost of building and maintaining of the system per person, smaller number of specialists from various fields being interconnected

Mixed Construction Type, Including Short-Term and Long-Term Stays on a Rotational Basis

This settlement system streamlines the previous two by creating variability of stays in ECH. The modularity of the structure allows to build an optimal hierarchy of spaces.

Places of concentration of people's social activities and the connection between them determine the planning frame of the residential area of ECH. The distribution of many open and closed building sites forms spaces that vary in composition, use and architectural organisations. That contributes to an increase in the intensity of use of the territories, the formation of zones of social responsibility, various scenarios of visual, functional, and pedestrian connections. The developed system of pedestrian connections stimulates social contacts and increases the variability of routes [15].

Community centres equidistant from the residential buildings, occupy an area of about 12 modules, which provides an easy access to a full range of services.

The territory is supposed to accommodate educational centres, service facilities, open cafes, areas for public events, holidays, and lectures (Figure 5).

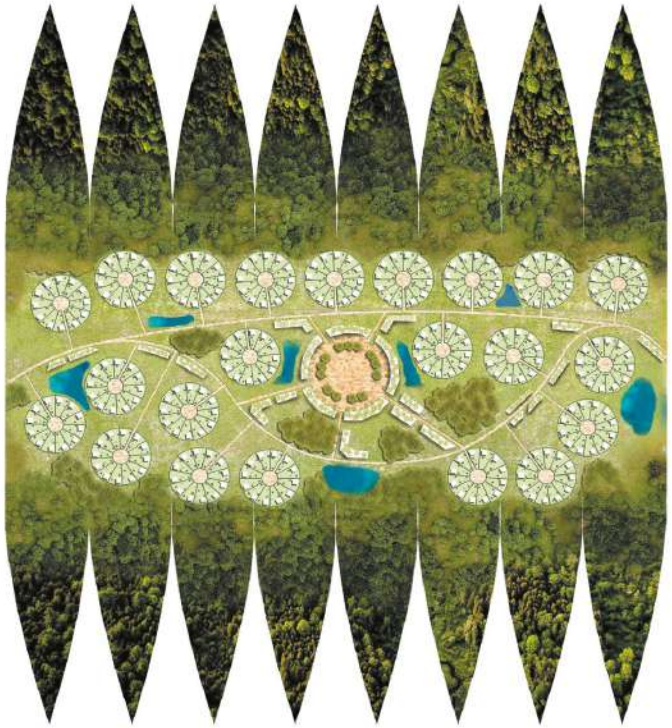


Figure 5 – Option of mixed development of the ECH inner cylinder (flat view

The polycentric structure of the public spaces, which characterises mixed construction type, forms a balanced living environment saturated with public, infrastructural and recreational facilities. The division of public space into small units helps to distribute the areas of responsibility among residents and provides a sense of belonging, community, and self-identificatio [13].

The community centres are surrounded by high-density hotel developments that will accommodate short-term tourists. On the hotels sites there are green areas added for recreation. Further, there are cells with single-family detached and row houses. The appearance and quality of the building materials of the houses must form a comprehensive environment that creates unity and diversity. House in this case has a purely conventional name, since it will be surrounded by a comfortable environment (in terms of natural and climatic characteristics), there will be no need for a foundation, insulation, and waterproofing, protection from heavy rains and hurricanes, heating systems and air conditioning and other elements of the terrestrial houses.

C. Conclusions and Future Directions of the Research

The internal organisation of the cylindrical touristic ECH, with its conceptual, natural and infrastructural components is capable of providing a comfortable long human stay in the outer space. The adopted capsule-based form of ECH that is a system of two cylinders, provides an increase in the usable area while maintaining the total volume. The distribution of functional zones makes it possible to efficientl use the surface of the cylinders, ensures the highest safety of space tourists and arrange logistics and products delivery inside ECH.

The inner space of the outer cylinder, including forests, fields, and meadows for farming, sports grounds, ponds and recreational areas, is able to create natural conditions for human habitation and provide necessary amount of vital products – food, drinking water, clean air, clothing, etc., as well as workplaces, research facilities, recreation and sports areas. The inner cylinder can accommodate a large number of tourists and provide high capacity, depending on the chosen mode of residence and the type of building development. The possibility of fl ghts in zero gravity, an unusual visual-spatial environment formed by a cylindrical shape, lower gravity, as well as different composition of the atmosphere will let a person experience living conditions different from the terrestrial ones

In the future ECH project development will be focused on a detailed programme of the necessary conditions for effective education and additional self-development of residents, as well as strengthening their health, natural recreation, and a unique experience of traveling in outer space. Further research might also focus on a detailed study of human adaptation process to the ECH environment, psycho-emotional state improvement, and synthesis of technologies that are able to provide the optimal functioning of an enclosed ecosystem.

It is equally important to create an optimal balance of a closed biological system as a single multifunctional living organism. Also, it is necessary to develop scenarios for the inhabited space cluster regulation, taking into account the constant flow of tourists as well as replacement or addition of elements of the natural ecosystem. These elements are borrowed from the best zone of the planet – subtropics with ideal natural and climatic conditions for living.

15.2 Specific Perception of ECH Inner Architectural and Space-Planning Environment

EcoCosmoHouse [2] is a space habitat with a shell in the form of a capsular cylinder. Such shape calls for new ideas of inner space organisation in order to provide a comfortable living environment for people. The required challenges include visual adaptation to an unusual cylindrical structure, calculation of a comfortable number of stores for the cylinder with a 300 m diameter, and creation of innovative design aimed to support healthy, environmental, and socially friendly condition in atypical conditions.

There are several modern international trends used in architecture. One of them is rejection of a multistorey mass housing. Foreign research indicates that low- and mid-rise buildings have positive effect on the mental state of the citizens, provide a better outdoor illumination and increase the useful life of buildings [16].

The next important tendency of the urban development is greening. The concept of an integrated improvement is based on landscaping and upgrade of urban areas [17]. This concept includes requirements to the reconstruction and geoplasticity of the terrain, planting of new trees, bushes and flowers in the streets and parks, installation of fencing, decorative lighting of the streets and residential quarters, placement of the small architectural forms and other city objects.

Separate studies are focused on obtaining of the environmentally friendly materials with the required strength and other characteristics. For example, Spanish scientists invented a bio concrete, which contains particles that allow it to retain all properties during the plant germination [18]. With the help of bio concrete buildings can be turned into vertical gardens without the need of additional flowerpots and pots. Magnesium phosphate is the main adhesion component in bio concrete that ensures favourable conditions for the mosses, lichens, and other plants while not harming the building structures.

Greening of areas and buildings together with the use of natural materials are the main aspects for creating an eco-friendly environment both on Earth and in the outer space.

Private construction projects carry trends to create communities of inhabitants using adequate space-planning solutions in residential quarters. Such solutions are aimed to develop good relationships between people from the same neighbourhood and create the main basis for a teambuilding. An illustrative example is the Garden City project in Copenhagen, Denmark, which is a collection of houses nestled inside a grid of perfectly circular greenery, thus creating neighbourhood communities with common rules while occupying rather small areas.

Above trends will be taken into account in creating an architectural and space-planning environment of ECH and exploring people's perception about it.

A. Adequate Design of Architectural and Space-Planning Environment

The creation of an architectural and spatial environment is a balanced, creative, and integrated process. There are rules that help to implement the architectural concept, such as harmony, style, artistic synthesis, shaping, plasticity, scaling relation, ratio system, rhythmic order, texture combination, subtle treatment of light and shadow, colour schemes, and tectonic arrangement. Moreover, the organic architectural shapes can blend in with the shapes of living organisms and natural landscapes, which helps to turn the environment and buildings into one whole surrounding. All these aspects are further developed in order to provide psychological and body comfort to a person, who enters the artificially created environment, as well as to keep this person healthy.

When designing buildings, facilities, and areas both on Earth and in the orbital ECH, it is important to consider the following different levels of optical perception of architectural shapes for correct and familiar perception of the surroundings [19]:

- if the object is in a panoramic environment, the acceptance angle is 18°;
- if the object is 100 % visible, the acceptance angle is 27°;
- if the object has detailed elements visible, the acceptance angle is 36°;
- if the object has texture and small details visible, the acceptance angle is 45°.

One of the main aspects of ECH is its environment-friendliness and nature-similarity. The main objectives of creating a natural environment are to keep balance between natural and artifi ial space elements, decrease consumption of resources and increase the psychological and body comfort of the ECH inhabitants by improving the functional, sanitary, hygienic, microclimatic, and aesthetic characteristics of the atmosphere, as well as by constructing buildings from materials that are not harmful to people's health and state of the environment.

Construction should also take visual ecology into account; the theory is about physiological vision standards and perception patterns. The proposed concept, as a new direction in science, helps to substantiate human preferences for regular shapes in architecture, design, and environment and to explain a subjective perception of art in general. Visual ecology has created an evidence base to measure aesthetic qualities. The design of the inner space based on visual ecology principles will contribute to the further development of ECH, as people living in a harmonious environment will continue to improve quality of their life and develop a proper settlement.

In order to perceive the ECH environment correctly, it is also important to consider the factors influencing human health [20]. Monotonous walls, continuous transparent panels, living "cells" and high building density may have a negative impact on eyesight and mental health, making people feel out of place and experience mental and bodily exhaustion in such environment.

Applied colour schemes are also important. For example, white colour is used for drawing attention to particular buildings or their parts. It also has a positive effec on human condition and increases person's energy. Green colour is the most natural and typical for our vision that can be found everywhere in the nature. It has soothing and stabilizing effect, while also lowers blood pressure, calms muscles, and actually relieves headache. This colour can be used in order to add diversity to the architecture of quiet sleeping areas of ECH and bring out the merging of buildings and natural landscape. Blue colour symbolizes patience and tolerance. It also closely matches the natural colour of sky and water, thus calming the nerves. Right colour solutions of the projected environment can affect the ambiance of its entire society as an unobvious tool for controlling the emotional state of people.

B. Ways of Forming a Space Comfortable for Perception

One of the issues in creation of a comfortable environment inside ECH is space distortion due to its cylindrical shape (the diameter of the cylinder is 300 m) in comparison with the typical placement of objects in terrestrial conditions (Figure 6).

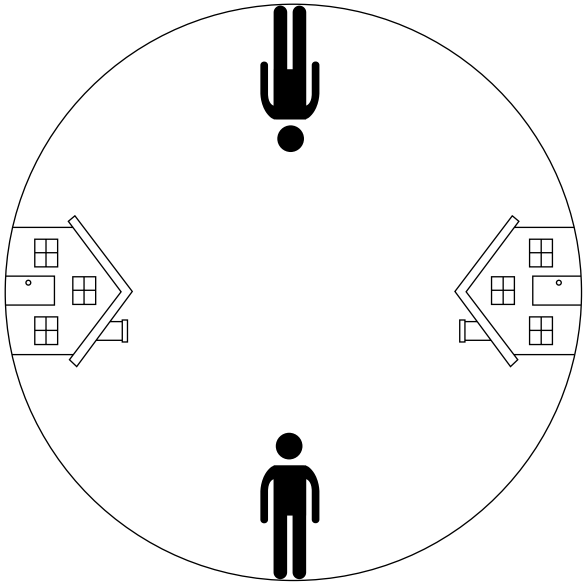


Figure 6 – Scheme of disturbed space

Such a shape of the ECH shell could make a person loss their sense of balance and environment perception: they would be surrounded by land from all sides, and the inclination angles of the objects would vary. In order to solve this issue, it is necessary to create optic illusions that can visually split the area. At the same time the specific shape of ECH which makes it attractive to Earth inhabitants would remain, enhanced with a comfortable environment for a permanent stay.

There are two main ways to change the visual perception of environment for comfortable life in ECH:

- choosing the suitable shape of a facility;
- geoplasticity.

Suitable Shape of a Facility

The main task is to choose and use the architectural shapes able to satisfy the set goal of creating comfortable, environment-friendly, and simple constructions that would not look inclined towards other objects from a distance. For instance, rectangular buildings inside the cylindrical ECH may look like angled or tilted depending on the distance and viewpoint.

In this case, the shape of facilities should be smooth and without sharp corners, in other words, bionic. Such a shape helps the buildings to blend into the natural environment, thus creating a more favourable and non-typical habitat. A good example is a dome house (Figure 7), that is convenient when being constructed on a curved surface and also nature-oriented due to its bionic shape. Moreover, dome houses have a whole range of advantages, such as energy-efficien , stability, fair price, eye-catching design, and optional interior design. Sphere is the most efficien natural shape: in comparison to a rectangular house, a dome house has 30 % less surface area, thus decreasing construction and decoration costs. Due to its shape, the dome house is almost five times stronger than classical structures

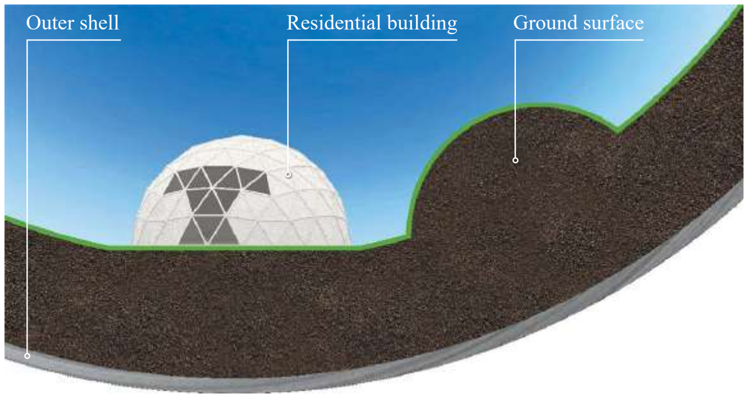


Figure 7 – Example of a building with a bionic shape

Materials for residential construction should be natural or with similar structure, like tissue, natural bamboo, lianas, breathable fabric, etc. It is also important to complement architectural compositions with lots of greenery. Natural plants would produce oxygen and useful phytoncids as well as bear fruits that could be eaten right inside the facility if it has, for example, a grapevine.

The main task here is to divide the ECH space not into standard houses, but into so-called rooms and separate isolated areas.

Geoplasticity

Geoplasticity helps to create natural barriers for movement and observation in form of hills and ravines, thus providing an environmental diversity and creating an Earth-like environment. The idea is to provide natural obstacles for vision, that can create an illusion of standing on an even surface in ECH (Figure 8).

There are two types of geoplasticity suitable for the ECH use:

- terrain alternation;
- terraced development.

Figure 8 – Example of geoplasticity: artificial embankment

Terrain alternation. The creation of a flat surface and location of buildings at the different levels of terrain (Figure 9), even "penetration" those constructions into the terrain, would help to artificially alter the micro space around people, thus distracting their attention from changes in the macro space.

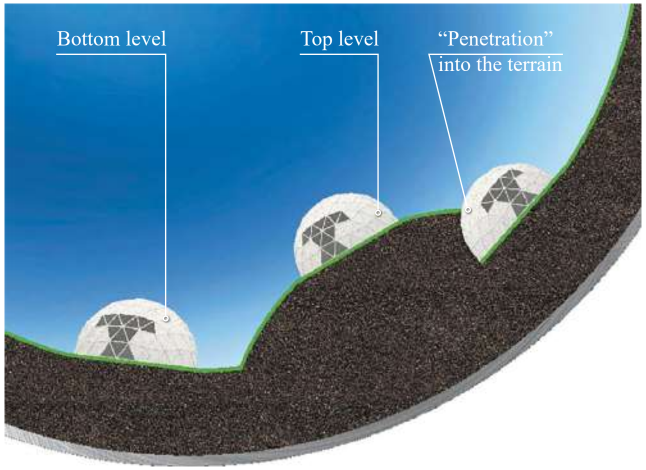


Figure 9 – Scheme of dome house location in the terrain

Terraced development provides a visual picture of the environment with its multi-level terraces and buildings being located on different levels, thereby hiding the entire space in general (Figure 10). Such a solution is also viable for the terraced fruit and gardens planting, thus changing the visual environment and increasing a useful area of the inner space.

Figure 10 – Scheme of the terraced development

The ECH space habitat is to be supported with the artificial gravity that tends to zero near the facility axis. As per calculation, buildings in the inner diameter (300 m) of ECH should not be higher than 16 m, because above this height people would face a drastically uncomfortable decrease in gravitation. Thus, the maximum building height is up to five floors or terraces. Low-rise buildings would also make ECH more comfortable for stay.

It is important to realise that the ECH inner space conditions could not be 100 % similar to the terrestrial ones, however, due to the right architectural solutions it is possible to create a comfortable environment even despite the unusual shape of the entire space.

C. Conclusions and Future Work

This chapter described the options to create a comfortable visual environment for the people inside ECH, taking into account its unusual shape. The main goal is to create a space with a favourable visual environment for the ECH inhabitants, using the accumulated construction and landscaping experience as well as applying various architectural techniques.

Nowadays there are no projects similar to ECH and it is therefore important to test the feasibility of all proposed solutions. Meanwhile, each solution has to consider the principles of ecology, use of biomaterials and autonomy of processes, as well as take into account the psychological and bodily comfort of people during their long-term stay. Having considered the modern methods used in construction, it can be concluded that it is already possible to create a comfortable environment inside ECH. Moreover, non-typical landscape, shape of buildings, and the whole organisation of the ECH inner space would become a unique and special feature of the project.

It is also important to further discuss other tasks related to the visual perception of the ECH inner space using the example of specific functional areas, as well as the influence of the ECH environment on its dwellers, in particular, how does artificial gravitation of the buildings and facilities heights influe ce a person.

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16

Principles for Establishment of EcoCosmoHouse on Planet Earth

16.1 Review of Possible Structural Solutions for EcoCosmoHouse on Planet Earth

Significant changes are proposed by the SpaceWay global space industrialization project designed to solve many exiting problems of humanity using the current technologies [1]. This project includes development and construction of the General Planetary Vehicle (GPV) and corresponding Industrial Space Necklace "Orbit" (ISN "Orbit"), as well as the Equatorial Linear City (ELC) and TransNet Global Network. All these elements are developed with the purpose to combine technologies, Earth's biosphere, and humans into a synergistic organism. One of the main steps in the system functionality is establishment of EcoCosmoHouse biosphere clusters (ECHs). These clusters are adapted to human needs in orbit and on planet Earth under adverse natural and climatic conditions.

One of the sophisticated problems in development of such residential cluster of a new generation is creation of the autonomous enclosed biosphere. This system should meet the requirements of all living organisms and correspond with the related processes, as well as be capable of maintaining a sustainable operation of all systems for an unlimited period of time. It was proposed to build EcoCosmoHouse on Planet Earth (ECH-Earth) as a prototype of a space residential cluster with an autonomous biosphere in order to test its operation. In this paper the authors discuss the construction features of the ECH-Earth dome structure to create an enclosed space. To achieve the target, analysis of the forms and their evaluation was performed to determine the development directions for the project.

There are several distinctive features of this facility that should be considered in the design process. Firstly, the construction should have a large span to envelop the area of about 2 ha specifi d to recreate various ecosystems – forests, meadows, mountains, and others for complex simulation of the existing biosphere. Secondly, the design of the structures should comply with the whole project design. The structures and their placement inside the facility should help a person to feel closer to the nature instead of feeling of being inside a closed greenhouse. Key elements of the ECH-Earth, including autonomous biosphere, hydro system, structural components and other modelled spaces, should look like natural ones and as close to the environment as possible.

To ensure, that developed facility provides the relevant environment for testing conditions, there should be a number of specific requirements applied to the design features. For example, at the first stage of the facility operation, the dome should consist of translucent structures to ensure survival, growth, and development of plants. At the same time, a technical option closing these windows should be also provided, as the autonomous interior lighting system of the biosphere should be tested during the second phase. This requirement is obligatory because during its construction in near-Earth orbit ECH will make one revolution around Earth in 1.5 hours, that is too quick to be a day or night for living organisms, including humans. However, the absence of translucent structures does not exclude the option of using Sun as a source of natural light. Such system should direct the sun light by mirrors into the internal space of the facility, as well as ensure energy generation for other needs of the space house.

Another key condition to ensure the experiment conduction is impermeability of the entire facility. This requirement should be fulfilled with respect to both the above ground section (the dome covering the biosphere) and underground part (heat- and waterproof pit with anti-root protection, containing the ECH-Earth base – soil and water systems). All components of the biosphere – air, water, micro- and macroelements, biological mass, energy, and their interaction – should be involved in full circulation inside the enclosed space and provide the self-sufficiency of the entire system. This requirement results from importance of absence of gas-, water- and other interchanges between the internal space of the ECH-Earth and environment.

The requirements for its structural parts are equally important. They should be resistant to changes in seasonal atmospheric pressure both inside and outside the facility; protect the internal space as much as possible from aggressive external influ nces (temperature changes, precipitation, biological threats, etc.); be non-fl mmable and made of environmentally friendly materials (that do not emit harmful substances during operation and easily recyclable at the end of life, etc.) with required durability (protected from oxidation, exposure to light and moisture, destruction by microorganisms). At any circumstance, presence of people and animals in ECH-Earth should be safe in all respects.

Research showed, that there is only one existing facility which is a full analogue of the ECH-Earth in terms of its structure and purpose and this is Biosphere-2. Space Biosphere Ventures implemented this project in the Arizona desert, USA, in 1991 [2]. The project purpose was simulation of an enclosed ecological system and identific - tion of human ability to live and work there. However, in this project the entire space of the facility with an area of 1.5 ha was divided into separate enveloped buildings with independent ecosystems. This approach contradicts to the concept and objectives set by the authors of the paper, that is creation of free space, which is natural and comfortable for living. It should simulate a miniature of Earth's biosphere with the best conditions and parameters taken for humans. There are no partitions on Earth, neither sharp transitions from one ecosystem to another: climatic zones flow smoothly from one to another, forests, meadows, water reservoirs, and mountains complement each other, and their interaction cannot be interrupted or limited. For these reasons, the abovementioned approach was rejected. Moreover, one of the initial ideas based on compilation of several geodesic domes as shown in Figure 1, was also rejected for the same reasons.

Research was focused on analysis of the constructions with large span, as the closest solutions for ECH-Earth. One of the existing solutions is the Tropical Island complex in Germany (an airship hangar redesigned into a tropical amusement park, which is the largest self-supporting hall in the world – its length is 360 m, width is 210 m, and height is 107 m) [3]. Another example is the Seagaia Ocean Dome, water park in Miyadzaki, Japan (an open dome with dimensions of 300 × 100 m, where air temperature is always above 30 °C, and water temperature is about 28 °C) [4]. Alternatives can be found in the Eden Greenhouse complex in the UK (it was constructed on the site of a former kaolin pit and performs tropical and Mediterranean biomes inside (divided into sections), this facility also employs computerized systems for maintaining the specified parameters for temperature and humidity, rainwater from the pit bottom, and energy from wind generators) [5]. Furthermore, another example of a large scale structure is the InterContinental Chengdu Global Center, hotel near Chengdu, China [6]. To some extent, the prototypes for the designed facility can be the Khan Shatyr, shopping and entertainment centre in Astana, Kazakhstan.

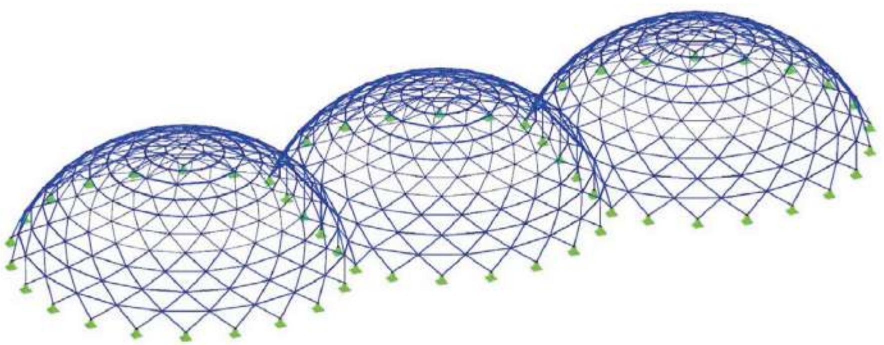

Figure 1 – Variant of the ECH-Earth structural solution – combined geodesic domes

This facility is the highest tent in the world that is listed in the Guinness World Records. There is a beach resort with plants and a temperature of 35 °C the year round on its upper floors. Another construction of the required scales is the National Centre for the Performing Arts in Beijing, China (more than 3 ha of space covered with a single dome without columns, half of it is made of glass). Finally, examples of the required structures can be seen in the Hangar One, hangar built in the 1930s to place the Macon U.S. military ship (its area is 3.2 ha, the height is about 60 m) [7].

All of the abovementioned examples have a number of specific features in their construction and operation. Assessment of these parameters can help in further design of the ECH-Earth. The structure should comply with the following general requirements: functionality; durability; maintainability and repairability; financial viability and eff ctiveness; power efficiency; and it should look aesthetically and comply with the environmental standards.

The main reason of large span structures installation is need in efficien utilisation of allocated interior area. As for the ECH-Earth project, possibility to remove intermediate columns and provide inside space organisation of the biosphere is an important criterion for the design solutions. One of the first options under consideration was the shape of a half cylinder (width – 120 m, length – 250 m, radius – 60 m) with hemispheres at its ends (Figure 2). The main cradle structure is a frame with a hinged supports. The required preliminary calculations of special models with applied loads were carried out according to the Euro code standards with the use of RFEM software package. Taking into account that the final location has not been determined, snow and wind loads that are typical of the Republic of Belarus were considered in the models.

A segment of the torus was analysed regarding its structure because ECH-Earth is not a separate project, but a part of the global SpaceWay subprogramme.

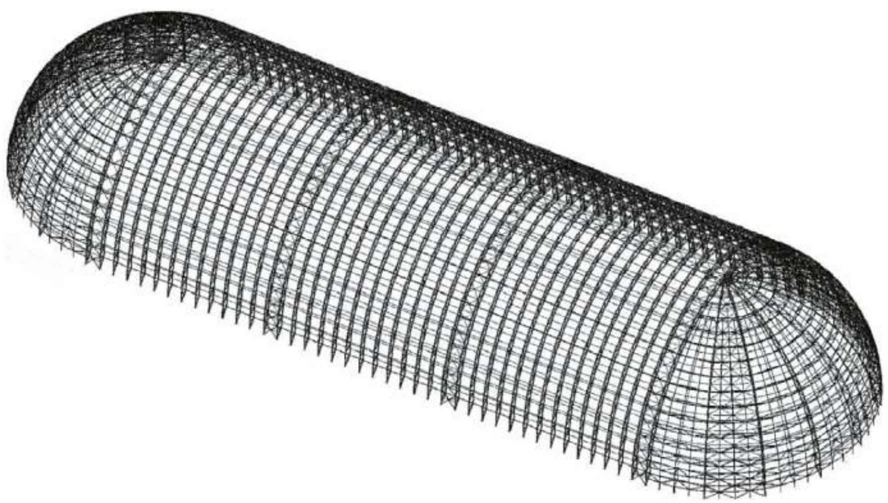

Figure 2 – Variant of the structural solution for ECH-Earth that is a half cylinder with hemispheres at its ends

This torus has an external diameter of 400 m (the element diameter is 100 m) and its inner one is 200 m. Dimensions of the planned fragment are 100 m (width) by 250 m (length), its height in the centre is 50 m and 4 m near the edges. The space is organised as cross-sections separated with the help of planes parallel to the rotational axis' plane at a distance of 150 m. An ellipse with a slight truncation at the ends of a large semi-axis is placed in plane (Figures 3, 4). The design concept of this option is a spatially framed structure based on triangular trusses with a height of about 6 m. All trusses have the same diameter, but each of them is inclined to the side along the curve contour of the torus' outer diameter. To reduce material consumption, an option of the similar solution as presented in Figure 5 with a height of 30 m has also been considered.

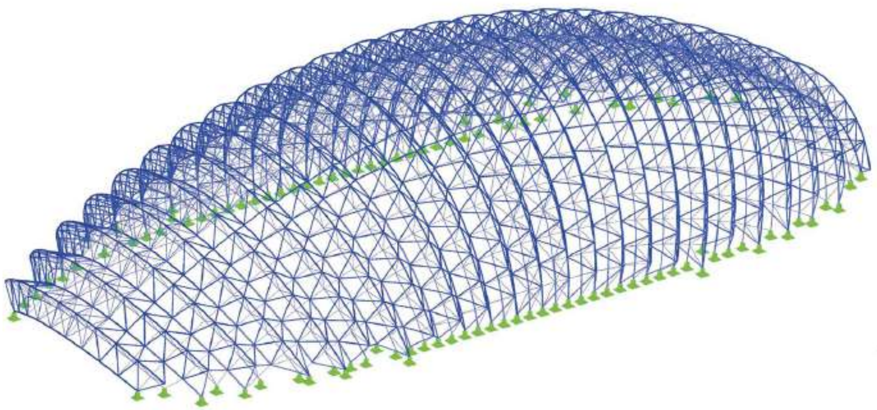

Figure 3 – Variant of the ECH-Earth structural solution in the form of torus fragment (height – 50 m)

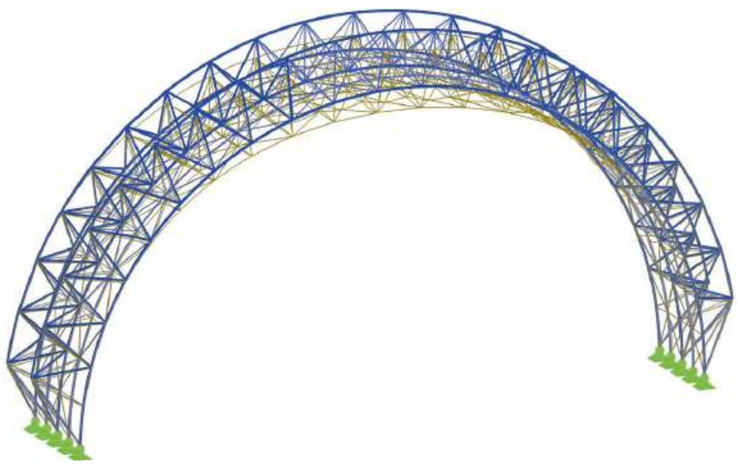

Figure 4 – Operation of the ECH-Earth structural solution
in the form of torus fragment with loads applied (height – 50 m)

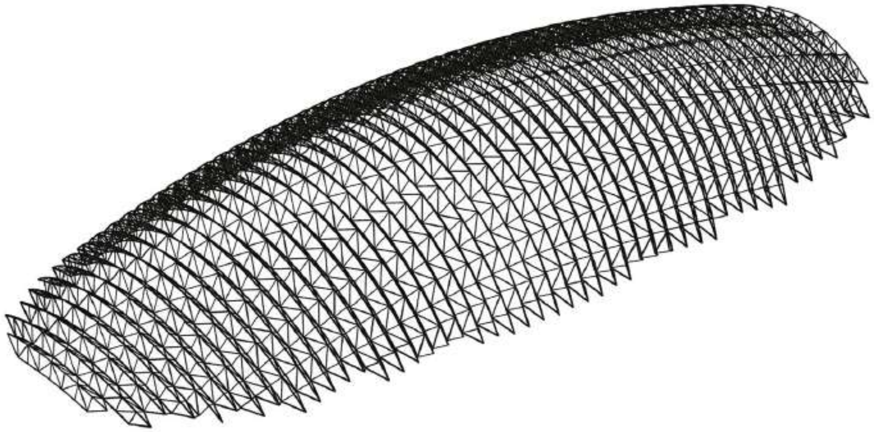

Figure 5 – Variant of the ECH-Earth structural solution
in the form of torus fragment (height – 30 m)

The next iteration of this solution includes substitution of triangular trusses with curved square beams (Figures 6, 7). The main disadvantage of such roofin in the form of a torus fragment is a high horizontal reaction force, which is transferred to the foundations. To reduce the consumption of materials, it is possible to combine the foundation and any area within the facilities.

Pyramids were considered as an alternative shapes of the solution, as shown for square foundation in Figures 8 and 9 and with rectangular foundation in Figures 10 and 11. It is possible to significantly simplify the structure by using basic shapes. Concept with a square foundation has dimensions 150 × 150 m, its maximum height is 50 m. It also includes centrally located building comprising a hotel and greenhouses. The design of this building consists of a reinforced concrete frame, which will support the inclined metal semi-arches. Dimensions of a hotel building/greenhouses are 30 × 30 m with a height of 40 m.

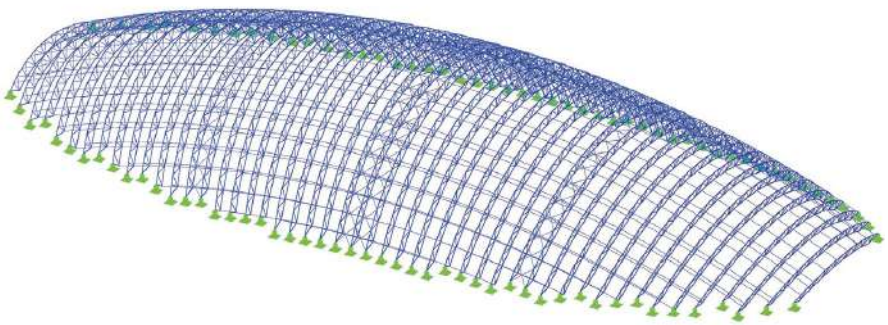

Figure 6 – Variant of the ECH-Earth structural solution
in the form of torus fragment made of curved square pipes (height – 30 m)

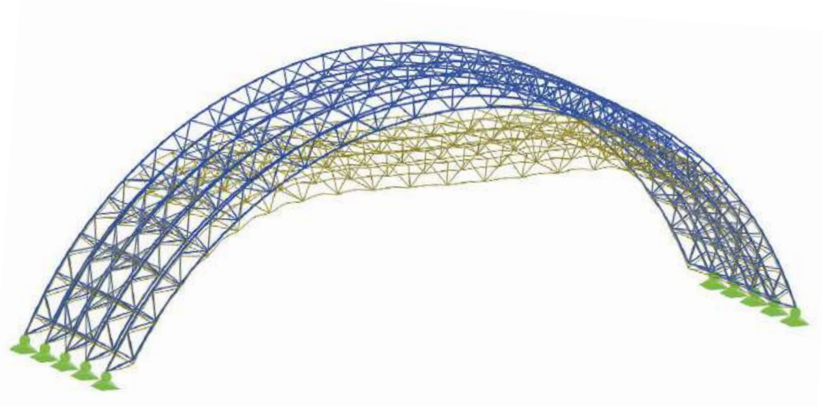

Figure 7 – Operation of the structural solution for ECH-Earth from torus fragment made of curved square pipes with loads applied (height – 30 m)

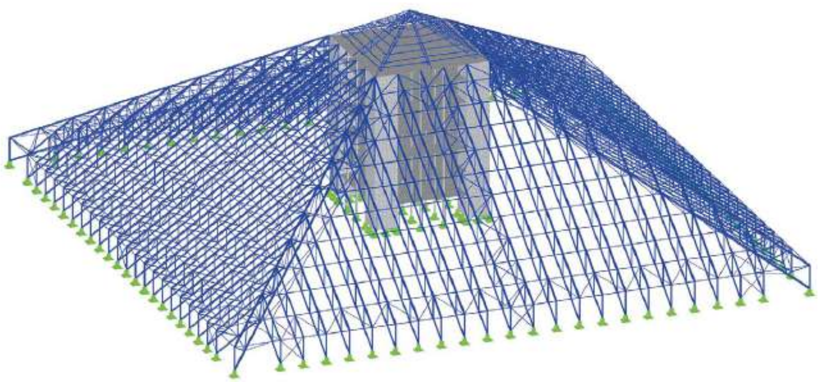

Figure 8 – Variant of the ECH-Earth structural solution in the form of pyramid

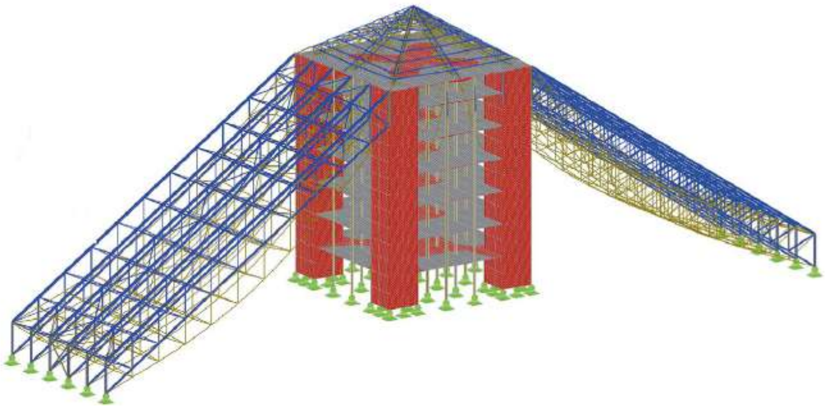

Figure 9 – Operation of the ECH-Earth structural solution in the form of pyramid with loads applied

However, this solution has a number of structural disadvantages: the basic height is given to a residential/public complex, and not to formation of the biosphere and integration into it; the square shape of the foundation makes it heavy to locate separate zones with luxury accommodations, lounge zones, service zones, etc.; there is no effect of the sky dome, and therefore, it does not meet one of the definitiv requirements – the space inside should be comfortable for an unlimited time period.

Dimensions of a pyramid with rectangular foundation are 100 × 250 m with the height of 35 m. Load bearing elements of the roofing are arches made of molded closed profiles. In this case, a hotel building is not connected with the roofing structure and it is easier to allot space areas; but aesthetically such a facility loses in comparison with the natural forms described earlier, for example, smooth bends of a torus fragment that looks like a mussel flap

Another concept with a natural shape was developed as one half of a torus fragment with the raised glazed roofing (Figures 12–14). The main structure supports in this option are transverse arch-like trusses made of closed mold-welded profiles and central columns.

To determine the optimal structural solution for ECH-Earth, the proposed options were compared according to the following parameters: area, volume, specifi

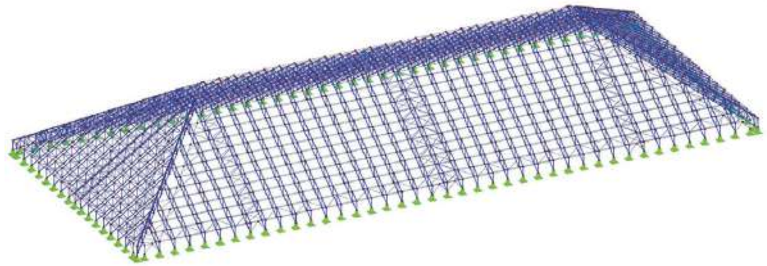

Figure 10 – Variant of the ECH-Earth structural solution in the form of pyramid with rectangular foundation

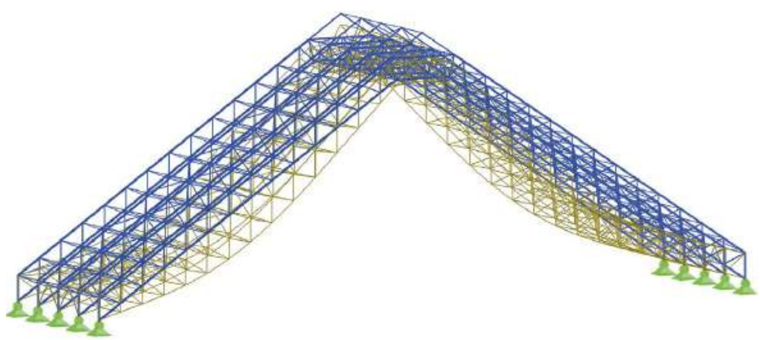

Figure 11 – Operation of the ECH-Earth structural solution in the form of pyramid with rectangular foundation upon loads applied

consumption of materials per 1 m^2 of the area, specific consumption of materials per 1 m^3 of the facility volume, cost of load bearing steel structures (Table).

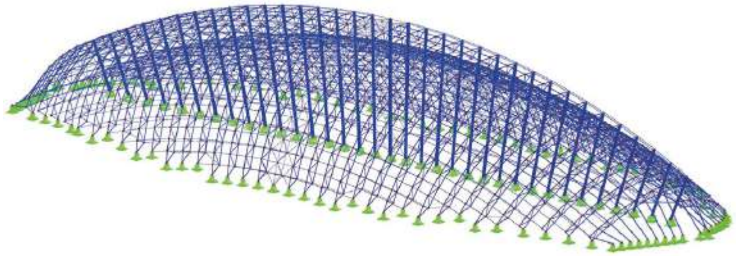

Figure 12 – Variant of the ECH-Earth structural solution with a raised part of roofin

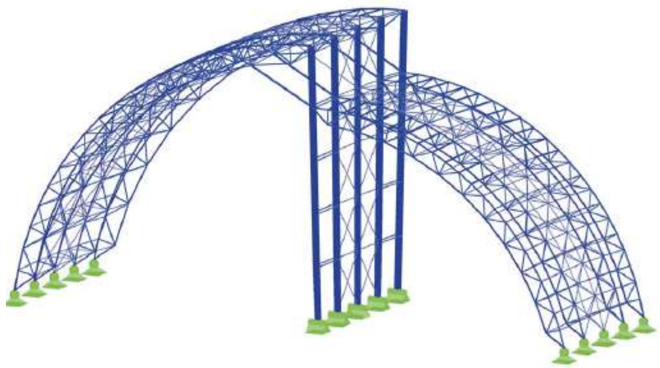

Figure 13 – Variant of the ECH-Earth structural solution with a raised part of roofing (fragment

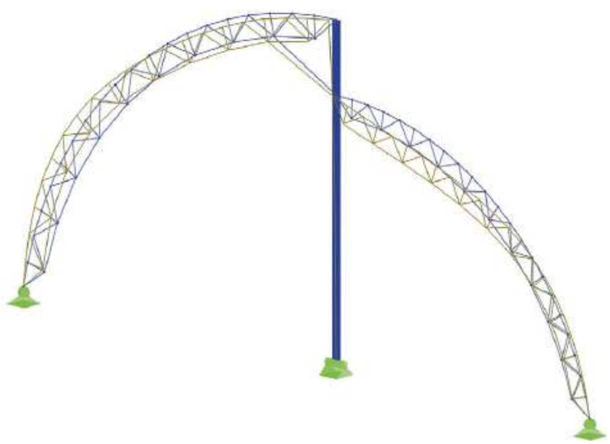

Figure 14 – Operation of the ECH-Earth structural solution with a raised part of roofing with loads applied

Table – Comparative analysis of materials consumption and cost of structures (as of May 2019)

Parameter	MU	Options						
		Torus fragment with a height of 50 m (roofin on triangular trusses)	Torus fragment with a height of 30 m (roofin on triangular trusses)	Combined domes	Torus fragment with a height of 30 m (roofing on separate trusses)	Pyramid (square foundation)	Pyramid (rectangular foundation)	Torus fragment with longitudinal section
1. Specific indicators per m^2 of the area								
1.1. Steel structures	kg/m^2	81	70	69	60	89	60	78
1.2. Cost of steel structures	BYN/m^2	415	369	360	319	452	305	405
1.3. Roofin	1 m^2 of the roofin / 1 м^2 of the area	1.87	1.5	1.45	1.3	1.36	1.28	1.37
2. Specific indicators per m^3 of the facility volume								
2.1. Steel structures	kg/m^3	2.8	4.74	3.62	4.11	4.17	3.37	3.33
2.2. Cost of steel structures	BYN/m^3	14.3	25.1	19	21.7	21.2	17.1	17.2
2.3. Roofin	m^2/m^3	0.06	0.1	0.08	0.09	0.06	0.07	0.06
3. Total cost of steel structures	BYN	9,170,626	7,924,961	7,339,670	6,868,300	10,169,728	7,627,296	9,305,902
	USD	4,367,098	3,773,906	3,495,188	3,270,719	4,842,875	3,632,157	4,431,517

The analysis results show that the most viable option is a torus fragment with a height of 30 m with trusses made of molded square pipes. Furthermore, this is one of the most aesthetic and nature-like forms from the considered options (Figure 15).

Figure 15 – Rendering of ECH-Earth (option)
with a structural solution in the form of torus fragment (height – 30 m)

A torus fragment with a longitudinal section and a raised part of roofing also looks attractively (Figure 16). However, since the height of a building rises, the consumption of materials, and the cost of load bearing structures significantly increase

Figure 16 – Rendering of ECH-Earth (option) with a structural solution
in the form of torus fragment with a longitudinal section and a raised part of roofin

These findings provide information to determine the development direction and take the up-coming steps in the project completion. Cost of the foundation was not included in the analysis, so it might have a significant impact on the final financial estimations and, consequentl , on the overall solutions ranking.

Alternative options are also under consideration (for example, variants with a fla roofing or terraces intended for public areas, plants, etc.). To obtain objective figures it is necessary to perform a comprehensive analysis with comparison of the entire solutions packages through a detailed study of all components of the ECH-Earth. Thus, it is very important to take into account all the requirements for the facility, recognize and demonstrate the necessary flexibility and innovativ ness of approaches in the rapidly developing world, as well as to realise the responsibility and prospects of the project in global programmes on space exploration and human civilization salvage.

16.2 Interior Design of EcoCosmoHouse on Planet Earth

Enclosed ecosystem creation has been highlighted in the last decade in various studies relating to the similar projects. These studies were conducted in order to develop a stand-alone object that could operate in the isolation on Earth or in outer space. EcoCosmoHouse on Planet Earth acts as an example of such-like object [8] and requires development of solutions allowing to combine various ecosystems for the balanced environment.

Due to the conducted studies related to the ECH-Earth construction, it is possible to apply the acquired experience to create objects with Earth-like environmental conditions on the near-Earth orbit.

Layout solutions are the tools to manage a whole range of various processes that influence interconnections between living forms within the ecosystem. The relevant functional zoning and layout of the sections have an effect on utilities location, landscaping, natural areas placement and, as a result, defin interconnections between various groups of organisms of the entire enclosed ecosystem. Correlation of space zones with respect to the trophic connections are a base for the zoning model, which can be then applied to various forms of inner enclosed space both on Earth and in outer space.

This paper aims to review development of the interior design for the isolated ecosystems supporting human habitation. Its main objective is to develop a space planning solution for adequate functional zoning for created trophic connections in the ECH-Earth which could be subsequently adapted to any form of internal enclosed spaces.

A. Examples of Created Enclosed Ecosystems

Worldwide experience in enclosed ecosystem creation includes only a few studies at this moment. BIOS-3 is an experimental closed ecosystem, which was developed by the Institute of Biophysics in Krasnoyarsk, Russia [9]. Its key space planning solution has the following features: relatively small size, structural integrity, life-support systems, and user-friendliness for the crew taking into account limited possibilities for interventions from the outside. Due to all these features, BIOS-3, among other artificial biological life-support systems, has become suitable for isolation of the crew (two-three people) during half a year providing closed cycles of water/gas by 100 %, and regarding food it amounted to over 50 %.

BIOS-3 was divided into four compartments, one of which was a crew area (three single-cabins, a galley, lavatory, and control room). Another compartment was an algae cultivator, while the other compartments were phytotrons, designed for growing wheat and vegetables. This structure could not assure comfort for human dwelling in the long-lasting projects in comparison with the conditions provided by ECH-Earth. Project did not comprise many natural processes, while the dwellers used only the minimum required resources to support their life. Moreover, neither livestock nor fish breeding were available inside the enclosure. However, a whole range of innovations in planting were introduced in the experiment [10, 11].

American company Space Biospheres Ventures, which in 1984 began construction of Biosphere-2, an enclosed Earth system science research facility located in Oracle, Arizona, USA [12]. Biosphere-2 is a structure with a square of 3.14-acre (1.27 ha, with volume of 200,000 m^3) that was originally built from glass, concrete, and steel. There is a 24-metre-long glass pyramid at its entry, and tropic forest is inside of it, while the other side of the created enclosure (16 ha) is occupied with an ocean, savanna, desert, and fields. Inside of Biosphere-2, water and surface ecosystems were artifi ially recreated: mini oceans with an artifi ial reef made of corals, tropical jungle, savanna, thorny woodland, desert, fresh and saltwater wetlands having a twisty riverbed flooded with the artific al ocean with planted mangroves.

You have to cross an air-tight entry enclosure, utility room equipped with sensors, and a lavatory connected to a recycling system to enter the dwelling area of Biosphere-2. Condensing equipment is located on the green (landscaped) roof of the dwelling module. The test module is connected to a filtration tank via the underground tunnel.

The biological diversity of the system includes about 3,800 species of plants and animals, counting hummingbirds, and lemur-like primates called bush babies, as well as various microorganisms. Biosphere-2 includes living apartments for "biospherians", as well as agricultural areas that comprise the Sun Space rancho [13].

However, a vast amount of areas in Biosphere-2 were absolutely needless and not equipped with any technical application, for instance, the deserted and oceanic sections. However, their maintenance required consideration and special conditions, as well as technical support. For example, it was hard to keep salt balance in the ocean: salt was absorbed by the surface, while its content in the water decreased. Declined salt content could result in mass mortality of fishes and other oceanic animals. Herewith, extra intervention such as ionization and activation of redox processes was required to support the adequate salt content [10, 14].

Tropical gardens were implemented to purify the inner air, while a swamp served as a hydrocarbons conservative system. All the generated CO_2 entered the tropical area, where oxygen was produced as a result of plants photosynthesis [14, 15].

So, the considered experiments of the enclosed ecosystems have served as a platform for further researches, however there is still no developed safe balanced environment for people to live there for the time periods exceeding two years. Implemented solutions did not contain definite number of functional areas, or, alternatively, some areas required special maintenance, that makes functioning of the enclosed ecosystem more complicated. Various interconnected elements are used in the ECH-Earth design, they facilitate life-support system, as well as placement of the areas is similar to the people's natural environment. Overall dimensions of ECH-Earth is chosen subject to safety and maintenance of the long-term stay of people in this enclosed ecosystem.

B. Requirements to ECH-Earth Space-Planning

When designing functional zoning of the ECH-Earth enclosed ecosystem, space-planning requirements, as well as biological requirements of the project, were considered.

Climatic and abiotic requirements. For the ECH-Earth ecosystem balance a subtropical climate was chosen as an optimal basis for a comfortable human habitat. In winter the temperature should be not below 15 °C, in summer it should be at the range of 20–27 °C above zero [16]. Daylight illumination in an enclosed biosphere should be based on the colour spectrum of the terrestrial sunlight.

One of the important stages is creation of artificial wind. Due to mass air movement, air will be evenly mixed and distributed across the entire ECH-Earth. Wind velocity may vary from 6 km/h to 23 km/h. This is a key factor supporting strengthening and development of the wind-pollinated plants.

Air humidity level should be within the range of 40–75 %. Extra humidity should be provided via natural moisture traps. Water coming from air dehumidificatio should be collected in freshwater container through extra filtration. Plants irrigation should be arranged on a daily basis with the use of deep groundwater. This process will be controlled automatically, including time rate of water application.

Water in ECH-Earth should be treated in two stages. Stage 1 includes removing of primary organic matters using algae and small animals (daphnids, amphipods, cyclopoids, etc.). Stage 2 means the process of water filtration through the special brook with the relevant water ecosystem which is filled with natural minerals of the specific chemical and fractional composition. Specifically designed length of the brook should meet the functional layout of the zones.

For sustainable growth of plants, it is necessary to provide the soil layer of at least 10-metre thickness on the ECH-Earth foundation structure. The soil containers for higher plants should be deeper than 9 m, while water ponds should have depth of 4–10 m.

Enclosed ecosystem area should be divided into planting sector, places for human permanent residence and industrial facilities [17].

Food production. This area is designed on a relatively small acreage and it is designated to cultivate agricultural products. It is important to isolate food products from technical and feeding areas. In order to provide rough grain for cattle feeding, it is possible to develop a cyclic harvesting with the cycle period of one month. Such short-term cycle will allow to reduce area, allocated for storage, and minimize grain rotting processes.

Animal breeding. It was suggested to place the main focus on breeding small animals in the conditions of the enclosed ecosystem. It is advisable to breed rabbits, goats, sheep, alpacas, quails, hens, and small predators. Small animals have quicker metabolic, that means quicker nutrition processes and movement of chemical elements within the enclosed ecosystem.

Additionally, fish and shellfish reserves should be created in the enclosed ecosystem. However, production of feeding elements for aquatic organisms is rather a complicated process within the ECH-Earth environment. It was proposed to arrange acceptable nutrition chains providing adequate delivery of the necessary elements and utilisation of algae, specifi ally, diatoms. Small shellfis will eat algae (freshwater shrimps, daphnids, amphipods, cyclopoids), and become feed for fish. Besides algae, some water plants would be cultivated in the water ponds to feed herbivorous fish. So, there will be balanced conditions for fish and shellfish breeding that will be then consumed by human.

Animal breeding objects should be separated from the living areas of people, as well as from the culture centres. Animals should be kept under adequate sanitary conditions subjected to the regular control. All the animals need some enclosures with dry humus for absorption of their wastage which should be cleaned once a week.

Architectural space planning and structural requirements. Based on the results, presented in [18], the best shape of the ECH-Earth is a sectioned torus with the height of 30 m. This shape of the enclosure is the most cost eff ctive and bionic variant being aesthetically acceptable to people (Figure 15).

The best option is to use spatial structures in order to create large covered area with no extra columns or other support elements, as shown in Figure 17.

Spatial structures enable creation of buildings with aesthetic appearance, while solving an issue with large spans, adding functionality and saving materials in comparison with the flatwork structures [19]

Due to its uniqueness, some special requirements should be met by architectural and space-planning solutions to ensure safe harbor of people because such class of buildings cannot be regulated by the existing standards.

Definition of the ECH-Earth composition in terms of the zones is based on the climatic and abiotic functions of the system, as well as required components to ensure biosphere balance, functionality, scheduled development, and economic factors.

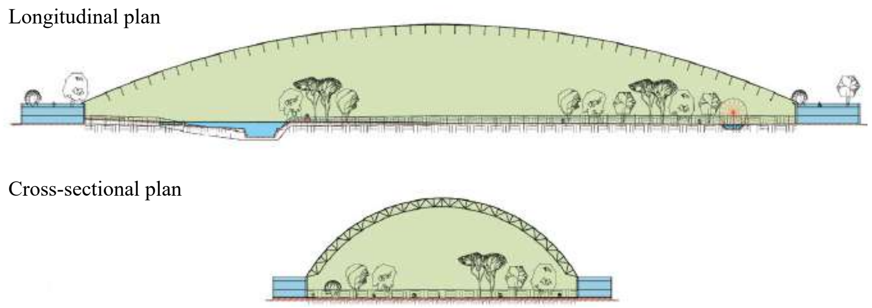

Figure 17 – Longitudinal and cross-sectional plans of ECH-Earth

Multiple use of the project facility, as it was initially planned, is also one of the significant factors in ECH-Earth functional zoning development. Hereby, at the firs stage of operation this complex can be used as a tourist attraction where visitors can come to ECH-Earth in various guided tours. At the second stage of functioning it will become a research centre with isolated ecosystem ECH-Earth which will be used to conduct the respective studies on its operation and further development.

Establishment of the enclosed ecosystem is subject to the concept of environmental compatibility and zero-waste production. ECH-Earth is intended to perform maximum biological productions and rational movement of elements inside the developed enclosed environment.

C. Functional Zoning of ECH-Earth

Total area of ECH-Earth is 22,564 m^2. According to the initially chosen design concept, internal space of the enclosed ecosystem occupies 20,142 m^2, while the hotel complex is located on additional 2,422 m^2.

Most of the ECH-Earth area is occupied by nature compound and it accounts to 40–50 % of the total area. Such percentage is based on the need to create in enclosed ecosystem natural climatic conditions similar to a subtropical terrestrial climate that will meet requirements for recreation, as well as energy and data cycles. Option of the natural and recreational park was chosen as a prototype of the ECH inner space which includes water zones (with fresh and sea water), water-thermal, forested park, meadows, agricultural areas, fruit and berry fields, livestock, recreational and beach (total 20,142 m^2) areas. Their correlation is based on the principles of the natural balance with respect to the tourist attractiveness. Food production areas are required for the enclosed ecosystem operation and they are located around the recreational area, to ease access to the food resources for the staff So, it includes fruit and vegetable gardens, green houses, laboratories, flowers greenhouses, repository of nursery plants, seeds, soils, petting zoo, and other elements. The key aspect is arrangement of organic production using highly fertile soils based on natural biohumus.

Water systems are one of the natural area sections occupying about 3,630 m^2 and containing fresh water pond, swamp, brook and thermal spring. Various content of water medium will create a microclimate suitable for breeding living organisms, fish, plants and provide various scenarios for the visitors' recreation and leisure, such as swimming, fishing, and rehabilitation in the thermal springs.

Developed system includes hotel rooms placed along the whole biosphere complex which will serve as living cells for scientists working in enclosed inner space.

Functional zoning scheme of ECH on Planet Earth is illustrated in Figure 18.

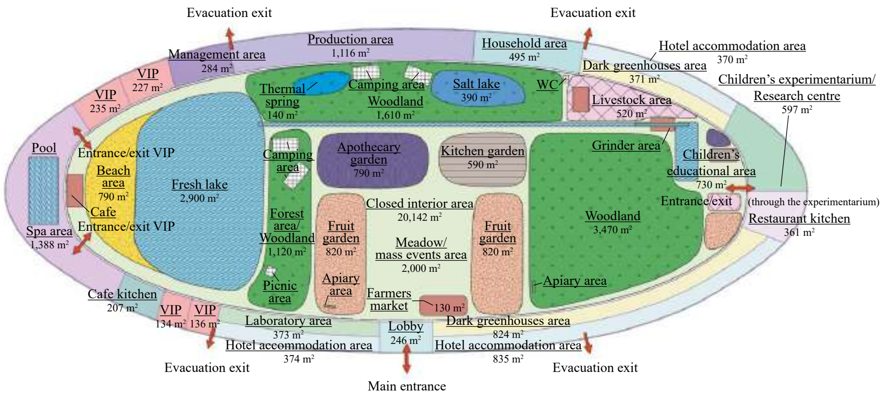

Figure 18 – Option of the ECH-Earth functional zoning

Hotel complex occupies 2,422 m^2 of the total space. Living area includes about 100 hotel rooms for tourists, including the suite rooms.

Public area of the hotel complex includes reception, lobby, communication unit, currency exchange office luggage storage room, change room, restaurant, meeting rooms, classrooms, shops, first-aid post, and other facilities required to ensure guests' comfort.

Sports and recreation area includes playgrounds, health walkway, swimming pool, and spa complex, herewith the visitors are able to keep healthy physical fi - ness during the rest period.

ECH-Earth also contains service, livestock, technological, production, and administrative areas, where the technical staff will live and work

General strategy of territory planning is based on correlation of open space areas of the enclosed ecosystem in order to perform control over natural balance and create a recreation park with various attractions for visitors. Besides that, an enclosed natural area can be fully isolated to conduct scientific research. Hotel area, technical areas and laboratories are designed as galleries, and serve for overlooking over the inner space of ECH-Earth, as well as this facilitates access and navigation through the territory. At the same time, it helps to restrict penetration of unwanted elements to the enclosed environment of the artificial ecosystem

The present solution provides opportunities for both scientific research of the enclosed ecosystem and development of strategy for the tourist complex for the project economic independence in future. The ECH-Earth advances a wide range of services as a hotel facility to create the most comfortable environment for its guests. For example, ECH-Earth will provide the following services: various food courts, relaxing, health-improving, and spa therapy areas, exhibition and conference venues, etc., as well as guided tours throughout the enclosed ecosystem created for the outer space habitation, climate therapy in subtropical forest areas, health walkways, trekking for people who need rehabilitation or strengthening of supportive and skeleton systems, camping inside the enclosed ecosystem, educational courses, study classes for pupils, students, and specialists with conduction of presentations and experiments in the enclosed ecosystem, laboratory tutorials, and markets for food and goods that are cultivated and produced within the complex, etc.

The abovementioned option provides accommodation for a large number of people while decreasing the necessary labour inclusion in the enclosed ecosystem operation.

D. Summary of Approach

The main goal of the ECH-Earth complex area planning is to gain the most effective employment of the complex. Created climatic and biological environment should be comfortable to a person and all life forms living there. The suggested space-planning solution contains a wide range of various ecosystems, both biological and anthropogenic, which combination is subject to close interconnection between all the elements of the created stand-alone biosphere. Operation of ECH-Earth as a research site will allow development of the necessary system balance, that then will be a basis for establishment of the ECH enclosed ecosystem in orbit, as well as space ships-colonies for long-lasting cosmic flights

The described project may activate prototyping of the tourist-aimed enclosed ecosystem in space habitats, such as, a tourist cylindrical ECH. Such infrastructure will create comfortable environment for the guests with unique recreational park, water zones, and food outlets. Flexible system of visits will facilitate access to various health tours to the enclosed biosphere, while enhancing economic stability of the project together with a wide range of scientific and research studies within the ECH-Earth premises.

Further research will be focused on detailed space-planning solutions, selection of plants and animals, production technologies for necessary household products within the isolated environment, including clothes, as well as development of a psychological control system for people, adaptation of functional zoning to various forms of enclosed ecosystems inside ECH-Earth.

16.3 Systems for Maintaining Optimal Climatic Parameters of EcoCosmoHouse on Planet Earth

One of the key problems in creation of an enclosed ecosystem, in particular for EcoCosmoHouse on Planet Earth [1], is to maintain specified optimal climatic parameters. These parameters are temperature, relative humidity, and pressure. The developed solution should also minimize operational costs. Specifics of controlling each parameter are discussed below in detail.

Aim temperature is the first task for the climatic maintenance system inside ECH-Earth. Northern subtropics climatic zone was selected for the given research. Temperatures fluctuation in the given conditions is 15–25 °C. It leads to the obvious conclusion that even ideal thermal insulation will not create required temperature conditions. Therefore, there is a need for an external thermal energy supply. For example, average annual air temperature in the Republic of Belarus is 6.1 °C.

From the point of view of the ECH-Earth concept, the most suitable external source of energy is sun due to its inexhaustibility and free-of-charge operation. However, for example, for the Republic of Belarus, the ratio of the average output power of photovoltaic panels to the rated one is approximately 1:10 [20]. In this regard, solar energy cannot be used as reliable source of heat energy. Therefore, it is necessary to consider other options. The simplest solution is gas-powered boiler system. The bottleneck of this source is the environmental constraints of the construction site, as well as the cost of heat supplied, which directly depends on the tariffs for natural gas. For Belarus, they are constantly changing and largely depend on the procedure for determining domestic Russian gas prices and on the political relations between Belarus and Russia [21]. Another alternative solution is the use of heat pumps. At present moment, such systems require significant investments, however, having high efficien . Another possible solution is based on the combined generation of electric and thermal energy through the brown coal gasifi ation. Thereby, the most advantageous solution means the optimal combination of diffe ent sources, allowing to minimize operational expenses and optimise capital costs. The ratio of sources depends directly on the ECH-Earth location. For example, when the system is placed on the Arabian Peninsula, solar energy will prevail, and when placed near coal deposits, the dominant technology will be the technology of coal gasification

The arrangement of the internal heating system is also a non-trivial task. Efficient thermal insulation is a necessary solution to reduce the load on the external source, and consequently, reduce capital and operating costs. One of the options is adding thermal insulation of a building. The minimum allowable value of the heat transmission resistance is selected based on the condition of non-condensation on the enclosing structures, which means that the temperature of the inner surface in ECH-Earth should not fall below the dew point temperature. The maximum value is limited by economic factors, such as lower operating costs per unit of thermal insulation to be added, taking into account the investment in this additional layer. The accepted insulation material should meet the required characteristics in terms

of cost, environmental friendliness, manufacturability, flammabilit , and a number of additional indicators.

For design of heating devices placements, it is important to consider specifics of heating processes in large-volume structures. When air is heated directly, the convective transfer of warmer flows to the upper layers of the inner "atmosphere" can cause the lower layers to remain cold. Furthermore, it will be impossible to achieve required temperature of the soil. Additionally, centrally placed heaters will cause an aesthetic problem, even providing uniform heat distribution of ECH-Earth. The obvious solution to this problem is to heat up the soil. Then, the air temperature will be maintained via heat transfer processes. This mechanism of heat exchange is natural, because in the biosphere, the sun warms the soil, and then the soil heats the air. However, in order to avoid overheating of the soil, an additional "classical" method of air heating is also required. It can be done using radiators and convectors.

Based on the above, the design process of the thermal supply and insolation systems for ECH-Earth should be treated with respect. Economic, technical and environmental factors should be considered together in the development process.

To maintain the required relative humidity, firstl , it is necessary to understand the mechanism of its changes. Considering the fact that any system tends to an equilibrium, in the presence of water in the liquid phase (for example, in the presence of water bodies), it will evaporate constantly, that will lead to the increased humidity. Air humidity will also increase due to transpiration phenomenon, i.e., the process of water movement through a plant and its evaporation through the external organs of the plant, such as leaves, stems, and flowers [22]. So, to maintain humidity, it is necessary to condense the moisture from the air. Physically, it can be accomplished by air-cooling. Technically, it is performed through using dehumidifi rs or ventilation. Technical solutions contradict to the enclosed concept of the ECH-Earth, so it should be excluded.

Large amount of condensate formation is inevitable when the humidity maintenance mechanism is deployed. According to preliminary estimates, about 10 tons of water will be condensed per day only from the surface of water bodies in ECH-Earth. Composition of plants and their vital activities will affect the amount of moisture, which enter the air via transpiration process for further condensation. Water from the dryers can be used, after minimal cleaning, for drinking purposes, as well as for plants' watering. These processes will become a part of the water circulation in an enclosed ECH-Earth system. The same approach for drinking water supply was implemented in Biosphere-2 [23].

Air pressure is another important factor. Most people react negatively to its changes as it leads to the changes in blood pressure. A rapid decrease in atmospheric pressure leads to the oxygen starvation of tissues (primarily of the brain) [24].

According to Mendeleev – Clapeyron equation, in the isolated systems pressure is directly proportional to the temperature [25], it means that rise or fall in temperature inside ECH-Earth causes a regular fluctuations of pressure. Daily changes process to mimic day-night mode will result in respectful changes in pressure.

Calculations show that when the daily temperature of ECH-Earth fluctuate in the range of 19–25 °C, the pressure fluctuations will range within 757–773 mm Hg. Annual fluctuations for the system will be in the range of 747–773 mm Hg. If living organisms are negatively affected by such fluctuation, pressure balancing solutions should be introduced using compensating volume approach. As an option, it is possible to reduce the range of temperature variation to ensure the required range of pressure variation inside ECH. Another requirement comes from the need to ensure absence of value variation between the atmosphere and internal air of ECH-Earth to reduce the load on the shell structures. The pressure difference in 1 mm Hg will produce an additional load on ECH-Earth shell in the amount of about 13 kg/m^2. For example, a diff rence of 20 mm Hg between pressures inside and outside ECH-Earth will create load, applied to the structure, exceeding possible loads from the snow or wind and in numerical values higher than 260 kg/m^2.

It can be concluded, that maintenance of optimal climatic parameters, as well as implementation of other EcoCosmoHouse systems, are extremely complex tasks. This statement is supported by attempts to create isolated ecosystems in the past. A striking example is Biosphere-2 – a highly technological structure for its time, but which did not achieve the desired result because the factors which might seem insignificant at first glance, but capable of provoking a chain destruction reaction of the entire ecosystem, were not taken into account. Further studies of climate maintenance systems should be aimed at determining the technical feasibility of the described solutions, as well as determining their technical, economic, and environmental indicators.

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17

Method of Recruitment of Specialists Ensuring the Effectiveness of EcoCosmoHouse on Planet Earth

17.1 Introduction

The United Nations (UN) recognizes importance of the outer space exploration with the purpose of its peaceful use and specifi s the active space exploration as one of the main tasks for the coming years, that is reflected in the report of the Committee on the Peaceful Uses of Outer Space to the UN General Assembly, 2018 [1]. The UN has set the objectives of deriving economic benefits from space activities, multiplying public goods, making space accessible to everybody, strengthening international cooperation and managing the space industry [2]. The UN also proposes to maintain outer space as an operationally safe and secure environment suitable for use by current and future generations and, importantly, recognizes that involvement of the private sector and non-governmental organisations will encourage introduction of innovative methods for space exploration.

Ideas for space exploration have still remained at the level of initial studies due to limited economic and technological capabilities of research organisations, growth of global problems on Earth and space race of states instead of developing a joint work on space expansion [3]. There are several reasons why space exploration and space settlements are necessary – from space exploration for tourism and search for inspiration [3, 4] to rescue and survival of humankind in the case of disaster on Earth and removal of harmful products from our planet for biosphere restoration [5]. The work on space industrialization should start in the nearest future, as evidenced by environmental problems arising on Earth (global warming, ozone depletion, world ocean pollution, destruction of tropical forests, desertifi ation, biodiversity reduction, depletion of natural resources).

With global industrialization of space, residential settlements for living in outer space, such as biospheric EcoCosmoHouses (ECH), are required [3]. However, before trying to build space settlements with an enclosed ecosystem directly in space, it would be reasonable to conduct a series of studies within the terrestrial conditions. To achieve this, a prototype of such facility – EcoCosmoHouse on Planet Earth (ECH-Earth) is planned to be implemented. The creation of ECH-Earth will allow developing the principles of a sustainable autonomous biosphere by conducting a sufficien number of experiments in an enclosed space in various fields of knowledge, science and technologies. Facilities of the ECH-Earth are designed to solve problems regarding comfortable stay of people in an enclosed environement with recreation of natural principles of the cycle of substances, energy, and information.

The problem of physical restrictions on the human stay in outer space (in weightlessness), due to the problems of muscle weakening and bone mass reduction, even despite special training and preparations, can be an example of the necessity of space sphere researches and creation of space settlements suitable for long-term human living [4]. It is important to conduct various research studies in various fields of science and technology, which can increase the time of human space stay in a healthy state, that in turn will lead to a significant leap in innovation development and economy growth [6].

The researches of various aspects of space exploration, colonization of Mars, Moon, and other celestial bodies with regard to creation of autonomous space settlements have been conducted over a notable period [4]. Thus, to understand the research tasks and the composition of teams of specialists, as applied to creation of the enclosed biosphere, the experience of the following experiments has been studied in the research:

- **BIOS-3 (USSR).** It is a 14.9×14.9×2.5 m chamber with two hermetically sealed compartments. A crew of 2–3 people lived in these compartments for up to six months [7];
- **Biosphere-2 (USA).** Glass hermetic facility of 12,750 m2, consisting of seven blocks (including – tropical forest, miniature ocean with unusual chemical composition, desert, savannah, and mangrove estuary). Eight scientists stayed there for two years in isolation from the outside world [8];
- **Closed Ecological Experimental Facility (CEEF) (Japan).** CEEF is an enclosed artificial ecosystem with plantings area of 150 m2, livestock module with area of 30 m2, residential module with area of 50 m2. There are no data available on long term experiments on human isolation in this facility [9];
- **Mars-500 (Russia).** This testing complex consisted of five experimental units: residential module – 150 m3; medical module – 100 m3; storage module with a greenhouse – 250 m3; simulator of Martian landing module – 50 m3; simulator of Martian surface – 1,200 m3. Six test engineers from Russia, Italy, China, and France participated in the experiment and spent 520 days in the complex [10];
- **Yuegong-1 (China).** Yuegong-1 facility with a total area of about 160 m2and a volume of 500 m3consists of three modules of semi-cylindrical shape. Three members of the first crew of Yuegong-1 spent 105 days in the hermetically sealed volume of the complex [11].

More detailed information on the above experiments can be found in subsection A of section 17.2 of this paper.

The indicated experiments have revealed significant problems (food crisis, loss of crops, difficultie in maintaining sufficien oxygen, growth of pests, natural utilisation of plant biomass, return of salts extracted from the human body into intra-system exchange, and many others) in creating an artificial biosphere. The modelling of an enclosed biosphere with a maximum number of different experimental processes, based on natural methods of circulation of substances, energy, and information, is a logical continuation of these studies to correct the mistakes made. This is possible to achive within the project ECH-Earth. To solve the tasks of forming an artificial biosphere, competent recruitment of research specialists is very important, and it is the subject of this paper. For these purposes, it is necessary to identify the key factors that influence formation of the project team made of researchers and test engineers. Based on the correlation between the found factors, the method for competent system recruitment of specialists in different fields, who will be able to solve the research tasks of the enclosed biosphere jointly and without external interference, was developed.

To achieve the goals of the experiment, it is necessary to ensure comfortable stay of the test engineers in an enclosed space, that will allow them to focus on the essence of the experiment to create an isolated biosphere without being distracted by side factors (providing themselves with resources, arramgement of working space). This conclusion prompted the author to study more deeply the human needs in conditions of high autonomy, as in the experiments described above, and to develop a method for recruiting test engineers for the ECH-Earth and later for the orbital ECH.

Several models of human needs exsist, including A. Maslow's hierarchical model [12], P. Kuznetsov's utilitarian classifica ion of needs [13], and others. The last one was chosen for further application in the developed method due to the convenience and logicality of identifying needs complexes and their grouping criteria (independent of each other, as in the Maslow's pyramid). The principles of building a comfortable human stay with the purpose of self-preservation (bomb shelters) [14], arrangement of territory for isolated living, education, and research (university campuses) have been also considered [15].

More detailed information about human needs and a comfortable environment for human life can be found in subsection B of section 17.2. Section 17.3 describes a method that allows competently recruiting specialists in diff rent fields to achieve positive results in creating the enclosed biosphere. The conclusions and further directions for research are described in section 17.4.

17.2 Literature Review

A. Experiments in Creating Enclosed Ecosystems

The above-mentioned experiments on creation of enclosed ecosystems considered the aspects which are necessary for development of methods for recruitment of test engineers, namely, the quantitative composition of researchers, their functions and professional skills, areas of experimental sites, and volumes of conducted tests.

Mars-500 was aimed at studying physical and chemical processes in an isolated environment, the impact of the enclosed space on the physical and psychological health of people, study of physiology, performance, and behaviour of test engineers in a simulated flight to Mars. The purpose of BIOS-3, Yuegong-1, and CEEF was to create an enclosed ecological system for human life support with autonomous control and to model the operational system of a spacecraft or an inhabited base on the limited areas. Biosphere-2 is currently the largest implemented project on modelling the enclosed ecological system. This experiment was created with the purpose to understand whether a human will be able to live in an artificial environment intended for colonization of Mars and it was built as a prototype of a shelter on Earth in the case of a global ecological disaster.

The Biosphere-2 project included eight people. The team was recruited from among those who were initially involved in the experiment preparation process. All the recruited specialist and their functions are summarised in Table 1.

The 12,750 m2 facility with various ecosystems (desert, tropical forest, agricultural field, and other locations) was built for the experiment. The bionauts had been there for two years. Test engineers were accompanied by animals, insects, reptiles to maintain ecosystem functions in an artificial environment [8 .

This project has the largest scale among existing ones. It demonstrates the complexity of biosphere reproduction and reveals the issues that were not taken into

Table 1 – Team of specialists for Biosphere-2 project

Test engineer	Functions
S. Silverstone	The financial and o ganisational parts of the project
M. Van Thillo	The technical part of the project
A. Alling	Professional oceanologist, director for scientific researc
L. Leigh	Botanist, responsible for Biosphere-2 flor
J. Poynter	Specialist in intensive agriculture, responsible for the farming and food supply to the colony
T. MacCallum	Technical assistant
M. Nelson	Head of irrigation and sanitation systems, responsible for transmitting information from Biosphere-2 to the outside
R. Walford	Doctor, responsible for research of health condition of bionauts at almost completely vegetarian organic diet

account during the object design and operation. For example, the farm in Biosphere-2 could not provide 100 % of food to bionauts, there were problems with oxygen, as well as pests had destroyed crops. There was an obvious lack of test engineers with different specialities: at certain periods all the bionauts had to do the farming and plant care activities. Hopes for using sunlight as the main source for ripening vegetable crops also failed: the weather over the testing site was predominantely cloudy, that affected the plants photosynthesis and, as a result, led to decrease in yields.

Ten experiments with crews of from one to three people were conducted in BIOS-3. The largest experiment lasted 180 days, four test engineers participated in it. V. Terskikh was in the facility throughout the experiment, the rest of the specialists changed in two months, as BIOS-3 was designed for only three test engineers (with respect to air supply).

An airtight room was built with dimensions of $14 \times 9 \times 2.5$ m and a volume of about 315 m^3. The cabin was divided into four compartments, there were phytotrons in two of them, the third one was filled with microalgae cultivators, and the last one contained crew cabins, household and auxiliary equipment. The engineer N. Bugreev lived in BIOS-3 for the longest period (with breaks and participation in several experiments) amounting to 13 months in total [7].

Due to the competent distribution of responsibilities, clearly defined tasks with the minimum size of the facility and the number of test engineers it was succeded to conduct a fairly large scale research, including food cultivation with a good yield, use of a catalytic furnace for oxidation of organic substances to eliminate suppression of the plants by chemicals, testing the conveyor system to ensure the entire life cycle of plants from sowing to ripening, the possibility of human residence among the plants in the conditions of a closed circuit. Test engineers reached full system gas and water shut down and covered the food requirement by 80 %. The small volume of the facility did not allow to conduct experiments with participation of animals, microorganisms, fungi and, as a result, to ensure the full cycle of the enclosed biosphere.

Three specialists took participation in Yuegong-1 experiment (Lunar Palace-1): X. Beizhen (crew commander), D. Chen, and W. Minjuan.

Yuegong-1 with a total area of about 160 m2 and a volume of 500 m3 consists of three semi-cylinder modules: an integrated work and living module (consisting of a work area, a companion cabin, three cabins, a personal hygiene room, a waste recycling unit and an insect compartment); two greenhouse modules, each of which is divided into two isolated sections. The stage of facility preparation for the experiment – testing of systems, planting of plants – had been continuing for two months.

In 2014, life support systems of the future lunar station Yuegong-1 were tested. During 105 days under conditions of the complete seal of the module the test engineers lived in the enclosed ecosystem. The food chains, as in BIOS-3, were built on the base of higher plants, animals, and soil decomposers. The researchers fed on plants grown inside the capsule (five types of cereals, 15 varieties of vegetables, one variety of fruits) and insects. Animal food and some other components were delivered from the outside through a special channel. Oxygen was produced by the plants; carbon dioxide was processed through photosynthesis. Waste products were used as fertilisers. Oxygen and water were 100 % regenerated inside the capsule. The test participants conducted several scientific and technical experiments [11].

As in BIOS-3, the researchers succeded to achieve certain results with proper distribution of responsibilities, but due to limited space, it was not possible to isolate the system completely from the outside world.

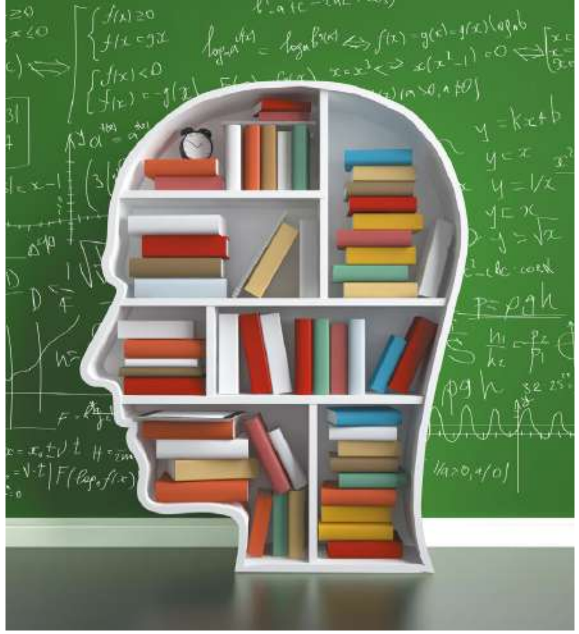
There is no data on the tests of human living in an enclosed ecosystem of CEEF facility, despite it was built with respect that two people will be staying there. It consisted of planting module (150 m2), livestock module (30 m2), and residential module (50 m2). The research was carried out in order to simulate closed cycles of gas exchange, water circulation, and power supply under the conditions of simulated Martian inhabited base. The results of modeling the consequences of global warming and studies of radionuclide migration in internal streams of substance were published [9].

This experiment, in contrast to Yuegong-1 and BIOS-3, included an animal module, that expands the number of studies and make the conditions closer to the initial terrestrial biosphere analogue. As of yet there are no results on human interaction under the conditions of this module.

Mars-500 project team included six people of different nationalities and professional skills. They were a practicing physician versed in emergency medical care; a research physician versed in clinical laboratory diagnostics; a biologist; an engineer versed in life support systems; an engineer versed in computer science; an engineer versed in electronics; and a mechanical engineer. This testing complex consisted of five experimental units: a residential module, a medical module, a warehouse module with a greenhouse, a simulator of Martian landing module, and a simulator of Martian surface. Before the experiment, the research programme, training, and background medical examinations of the test engineers were completed.

During the simulated flight the crew members were monitoring their physical and mental health, environmental parameters (pressure, temperature, humidity), and consumed resources (food, water, consumables, spare parts, life support systems resources), regularly carrying out preventive regulatory and repair work to maintain the normal functioning of the modules systems, as well as sanitary and hygienic measures, including toxicological and microbiological control [10]. The research programme, which had been developed prior to the launch of the project, made it possible to accomplish the experimental tasks and test the landing on Mars and return to Earth.

The reviewed studies have accumulated certain experience (both positive and negative) in modeling certain parts of the artificial biospheres. Further, it is necessary to create a complex covering the full range of all systems and allowing to maintain a closed cycle of substances, energy, and information in a limited space for a long time. In turn, to research this enclosed complex, it is necessary to create a comfortable environment for effective work of the test engineers



B. Factors of Researchers' Work Efficiency

After studying artificial biosphere creation facilities, the modern experience in approaches to human needs systematization to meet them in conditions of an enclosed space was considered.

The following main needs according to A. Maslow's pyramid were considered [12]: physiological (needs for food, water, shelter, and rest); safety (personal safety, health, stability); belongingness (love, friendship, communication); esteem (self-esteem, respect); self-actualization (improvement, development).

An alternative to this concept is P. Kuznetsov's utilitarian classification of needs [13]. Due to the convenience and logicality of the identified complexes of needs, criteria for their grouping, and factors of satisfaction presented in the modern society, this classifi ation was chosen for studies in the specifi d conditions of enclosed spaces. Seven combinations of needs were formed on this basis: economic, regulatory, self-preservation, reproductive, communicative, cognitive, and self-actualization ones.

For the economic complex of needs, the grouping criteria are money and its equivalents, whereas availability of wages, benefi s, dividends, savings, and jewelry are the factors satisfying them. The regulatory complex of needs is grouped according to the criterion of human organism functioning, and the most important factors of their satisfaction are health condition, climate, work and rest regime, living conditions, as well as emotional state of a person. The self-preservation complex is based on existence security, the satisfaction factors are criminal situation in the living environment, loss of the source of income, infection suffering. The reproductive complex is based on functioning of a family and sexual relations, the satisfaction factors are birth and upbringing of children, care for loved ones, sex. The communicative complex is based on the criteria of communication and information exchange, and the satisfaction factors are relations with relatives, colleagues, friends, availability of TV and radio programmes, and print media. The cognitive complex of needs has its criterion of learning something new; the satisfaction factors are education, professional development, scientific research, travel, joining the art. Finally, the self-actualization complex is based on the highest achievements of an individual in various fields and the satisfaction factors are creativity, skill, superiority in something, authority, achieving the meaning of life, faith in God, and much more.

Campus, as a type of an isolated territory with a set of main facilities for comfortable stay of people and satisfaction of their needs, was chosen for researches due to the similarity of different scientific activities, as well as people of different nationalities being living in it with different experiences in orders, traditions, mentality, professional qualities, specializations, and directions for study. Modern world universities try to organise suburban local campuses, which are characterised by safety, isolation, low density of territory development (80 people per 1 ha), and high quality of landscape environment. Based on statistics this type of campuses is the most suitable for scientific progress and educational activity. Sustainable development of the campus is formed by many features: an effective concept of its organisation

and further activities, a separate territory, attractive architectural and spatial concepts, a "green" environment, transport availability, low (comfortable) occupation density, security (technical and social) [15]. It is important that enclosed space should be formed subject on goals and tasks have to be solved in it. Objects of this kind should provide feeling of comfort together with safety and occupation density.

The need to provide a comfortable environment for people in stressful situations has led to study of facilities meeting high safety requirements – high-capacity bomb shelters [14]. This resulted in paying attention to the social and psychophysiological microclimate in the ECH-Earth and creation of favourable conditions for people of diff rent social classes, ages, psychological and physical states in the enclosed space. For a long comfortable stay of people in specifi structures, it is also necessary to consider their need for full employment to feel a normal course of life and to maintain a stable psychological state.

It is obvious that one bionaft will not be able to provide all the resources to meet the above-mentioned needs. To form the resources necessary for existence in ECH and to control all systems providing autonomy and life support of the whole complex, the teamwork of researchers is required. Competent method of recruitment of specialists will allow optimising time resources to solve the tasks having applied people's skills in various fields of activit .

17.3 Method Description and Analysis of Its Effectiveness

The main purpose of ECH-Earth creation is to conduct scientific researches on the enclosed biosphere as an analogue of space settlement. The main goal for the people, who will be residents of the ECH-Earth facility, is to live under conditions of high autonomy while providing themselves with everything needed and maintaining the system complex in optimal operating conditions without help from the outside. Within the framework of the experiment on living in such enclosed system, the communication with specialists from the outside can only be carried out to get advice on the specific situations that cannot be solved within the ECH-Earth.

Based on the idea of artificial biosphere creation and considering the existing studies and experiments at similar facilities, taking into account the basic human needs and criteria of the comfortable environment, a method for determining the minimum sufficien number of skilled test engineers for their comfortable stay in conditions of high autonomy of ECH-Earth, and further in the orbital ECH, has been developed in this project.

Considering the technical capabilities of the modern world, the maximum possible scope of processes in ECH-Earth should be automated (for example, maintenance of temperature conditions, tightness, quality composition of the air environment), that will reduce the number of required personnel and tasks for them, as well as to focus the attention of the specialists on experimental work. Nevertheless, it is necessary to control many technological processes, biological and technological systems whithin the complex, for example, the processes of transformation and distribution of energy flows, providing sustainable self-sustainment and self-regulation of the facility, the system of biological metabolism, as well as to optimise processes of growing various cereals, vegetables, fruits, and berries (planting for continuous harvest), to conduct alternative experiments on waste management and many others. The systems should be maintained in operable condition for an unlimited period and act as a back-up for a long-term stay of people at the facility. The artificiall created biosphere should be highly controlled by the man, it is impossible to rely on its full self-preservation as it happens in the Earth biosphere. At the same time, it is necessary to recreate its conditions by copying the natural processes so that its further development would follow the natural pattern. Biosphere-2 demonstrates neseccity of this statement, because the project did not take into account the trophic chains, and, as a result, the entire yield was destroyed by breeding pests. It is necessary to create an anthroposphere with a compromise interaction of human and nature.

Local experiments in various scientific and technical fields ca ot give complex results applicable for creation of the enclosed biosphere, and this makes the ECH-Earth project a unique one. This complex is a comprehensive system, where specialists from various specialities, including technical, biological, chemical, medical, biophysical, biochemical, radioecological, and other fields, interact with each other. Also, in contrast to similar relatively successful projects described above, the ECH-Earth is greater by several fold in its area and volume. This also imposes its challenges in keeping all systems in optimal condition. But, on the other hand, this volume allows us to step up in the experiment and perform more experimental and scientific high quality researches.

For comfortable work of the specialists in the described conditions, the human needs are considered according to the conditions in which they will be located (Table 2).

Based on the analysis of Table 2, the needs are divided into those that will be met during the ECH-Earth construction and will not require additional human resources within the facility in the course of the experiment (a set of economic, self-preservation, and communicative needs), and those that must be considered when forming the team of the ECH-Earth and ECH to ensure a comfortable environment and productive work (the complex of regulatory, cognitive, and reproductive needs).

To determine the number of skilled test engineers and researchers for ECH-Earth, it is necessary to link the functions necesssary to meet the human needs with the professional skills required to supply that. It will provide determination of the minimum amount of human resources required to conduct a set of researches, ensure the maximum work for test engineers and researchers, and prevent overload of the ECH-Earth with technological processes in the case of unsufficie quantity of the personnel (because of limited space). Structuring the necessary skills of ECH-Earth's specialists will ensure a balance between the limited number of the test engineers, the set of technological processes, and the space allocated for this complex (Figure 1).

Table 2 – Human needs with regard to ECH-Earth conditions

Complex	Criteria	Factors	Conclusion subject to conditions
1	2	3	4
Economic	Money	Salary, benefits dividends, savings	When conducting tests on the territory of ECH-Earth, there is no need for money (for example, the salary fund will be accumulated and paid after the end of the experiment). The conditions created inside should facilitate teamwork and cooperation (each researcher does for his colleagues the part of work entrusted to him). This can also be a factor in meeting economic needs
Regulatory	Functioning of the human body	Health, climate, work and rest schedule, living conditions, emotional health	On ECH-Earth territory, all conditions will be created for the normal body function, good emotional state, healthy work and rest regime. Comfortable living conditions will also be created by the project. A profound medical examination of all candidates will be conducted before the tests. Interaction with the outside world will be arranged to resolve unforeseen situations (serious illness of the test engineers, etc.). It is necessary to select the relevant specialists responsible for health of people (physical and psychological), regulation of the processes of living and rest, physiological needs (nutrition, rest, physical activity)
Self-preservation	Security of existence	The criminal situation in life environment, loss of a source of income, infection	The research programme, team, and conditions of stay in ECH-Earth should eliminate the people's anxiety over safety. The fear of being left without external support and lack of opportunity to solve problems with internal resources should be compensated through competent recruitment of the specialists, whose competences cover the main responsibilities for life support in the enclosed space
Reproductive	Family functioning and sexual relations	Birth and upbringing of children, caring for loved ones, sex	The group of the test engineers will be in an enclosed space for a certain time. Therefore, there is no need for family organisation, and communication with loved ones will be carried out through modern means of communication. In the case of long experiments participation of the whole families is possible in the study

The end of Table 2

1	2	3	4
Communicative	Communication and information exchange	Relationship with relatives, colleagues, friends, availability of TV and radio programmes, and print media	Communication with relatives, colleagues, and friends, information exchange and access to it will be carried out through modern communication means. It is also necessary to create a team of the specialists who will be close to each other in interests, in order to maintain friendly relations
Cognitive	Learning something new	Education, advanced training, scientific research, travels, introduction to art	The experiment objective is to provide life support for the enclosed space and conduct scientific research in various areas. This objective and understanding that this experiment is a step up in both research and technology, will be an incentive to meet cognitive needs. Also, initially the research participants go to the project to meet their cognitive needs
Self-actualization	High achievements of the individual in various field	Creativity, mastership, superiority in anything, prestige, achievement of life purpose	ECH-Earth and ECH creation imply organisation of a separate territory with its social structure and social principles, where everyone can find his niche and place for self-actualization, achievements of the life purpose, manifestation of creativity and skills. The project by itself means making the grades in various areas

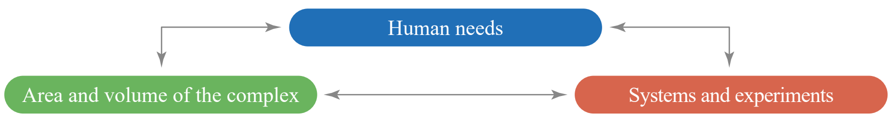


Figure 1 – Dependence of factors ensuring comfortable stay of specialists in ECH-Earth

Comprehensively, to form the team of the specialists, it is necessary to consider the following:

- schedule of the experiments and research activities (should be developed at the facility design phase before determining the team of the test engineers);
- technical components of the facility – artificial hydrosphere, wind generation, closed waste recycling system, plant watering, air quality control, other systems (should be determined at the detailed design phase);
- engineering systems maintaining comfortable living environment (temperature and humidity conditions; degree of illumination and its intensity (on an individual basis for people, animals, and plants); heating, ventilation, and other means and devices should be determined at the detailed design phase);

- the quantitative and qualitative composition of plants, animals, insects, microorganisms, fungi, and others (to be determined at the detailed design phase);
- other components that will be determined during both the design phase and preliminary open mode tests.

The optimal density of ECH-Earth occupation mostly depends on the ability to provide people with food, water, and air. This directly affects the number of researchers, that in turn affect the scope and speed of internal experiments and the number of automated technological processes. Overloading the ECH-Earth with systems and internal experiments can result in negative consequences (psychological, moral, physical) for the test engineers, that will aff ct the fin l result and lead to a negative outcome of the entire experiment.

Figure 2 shows factors and their key indexes affecting the successful completion of the research missions in this type of facilities.

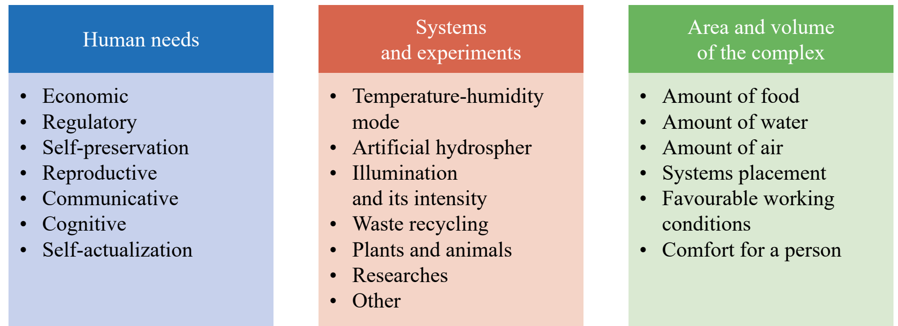


Figure 2 – Factors and their key indexes affecting the successf l completion of the research missions within the ECH-Earth facility

The dependence between the above factors highlights that designing of ECH-Earth as an enclosed biosphere "test site" should be firs of all based on the sufficient number of specialists, who will ensure the operable condition of the facility from the inside for an unlimited period and at the same time will be provided with everything needed for a healthy life.

The consolidated sequence of the method for recruitment of the specialists, who ensure the efficiency o EcoCosmoHouse on Planet Earth, is as follows:

- determination of ECH-Earth dimensions (area and volume) during the predesign study;
- development of functional zoning (space division and distribution of all engineering systems, technical components of the facility, areas for planting, water objects, placement of animals inside ECH-Earth to ensure operability and effe - tiveness of the structure and meet the specialists needs), basic planning solutions for the facility;

- calculation of quantitative components of basic human needs (food, water, air), the maximum possible personnel number will be determined subject to this calculation within a certain area and volume of the facility;
- development of a test schedule with distributed responsibilities for each specialist according to the research items and including control of engineering systems and factors influencing the meeting of the people s needs inside ECH-Earth;
- when parameters do not match (for example, lack of the research specialists), a weak point must be identified (for example, limited number of researchers because of insufficient food

  Thus, if there are too many tasks the researchers may not be able to control the technical components of the facility and pay due attention to the experiments because a great amount of time has to be spent on providing themselves with the bare essentials for survival. Overpopulation of the facility with a given area may raise questions with the comfort of living, lack of water, food, and air. Ignoring of human needs (poor living conditions and climate; uncomfortable working conditions; lack of progress, growth, certain achievements; lack of communication with relatives) will result in psychological discomfort and lack of desire for further researches. The described problems are only particular examples of negative consequences of the imbalance between quantity and quality of tasks and personnel performing them. Even one of the described situations may lead to a negative result of the whole experiment and, as a consequence, mean return to the initial phases of the project implementation;
- improving parameters that are weak points (for example, methods of food production or areas used to grow food using rearrangement of functional zones or by increasing the facility);
- when all required parameters are balanced, the detailed design works should be started as further implementation stage of the project.

17.4 Conclusions and Future Work

The dependence between three main factors in forming the composition of the researchers is determined as follows: human needs, systems, and experiments, area and volume of the complex. The method structure has been defined and it will allow in the course of the detailed design of the facility competently recruiting the specialists in various fields to achieve positive results in creating the enclosed ECH-Earth biosphere and maintaining its systems for an unlimited time.

Hereafter, at the phase of the complex detailed design phase, the list of professional skills of ECH-Earth specialists will be defined with description of their necessities and layout by different categories (blocks). Based on the reviewed labour costs of the specialists regarding particular tasks, methodological guidelines should be developed in order to form the research plan, which will provide the maximum work involvement of the test engineers and protect the whole experiment from force majeure circumstances related to the lack of time resources needed to solve the given tasks.

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18

United Digital Economic Model for Management of EcoCosmoHouse on Planet Earth

18.1 Introduction

A project investment attractiveness is traditionally assessed to evaluate investments effectiveness. However, for sophisticated, complex facilities, such as EcoCosmoHouse on Planet Earth (ECH-Earth) [1], the project's success depends on both economic factors of the external environment and components of the facilities operation. Operation processes include functioning of an enclosed biosphere inside ECH-Earth [2], or the use of solar energy to ensure power supply of the facility [3], or ensure that the facility is self-sustained that allows creating ECH-Earth on inhospitable terrains, and further in the near-Earth orbit. All these factors should be evaluated and considered not only in terms of physical processes in the facility, but in terms of their impact on the project investment attractiveness and changes in its market value.

The authors of this research proposed to use the approach of Big Data technology to assess the investment attractiveness of the ECH-Earth project. This is a sophisticated multifunctional infrastructure complex. It uses technology that includes enclosed autonomous ecosystem with a full circulation of substances, energy and information, that reproduces natural processes and uses natural soil microflora and microfauna, thus ensuring eco-favourable environment for human habitation [4]. To assess investment attractiveness of ECH-Earth, a united digital economic model was created, with its upper level being based on a database with over 100,000 values collected under nine structural design options.

Unlike traditional approaches to assessing investment effectivenes of infrastructure projects, where a large number of external [5] and internal [6] factors affec the final figure, with challenge of accurate evaluation of all conditions, which additionally are hard to analyse with respect to the project risks. The proposed method allows collecting a high volume of data and simulating various scenarios by identifying the values based on the requested parameters and using the required formula for calculation [7].

This approach provides a new quality of the generated information and sharpens competitive edge of ECH-Earth over similar projects. The authors share the view of many researchers [8], who has stated that Big Data analytics provide a strong competitive advantage. Herewith, over 90 % of analysts believe that successful Big Data initiatives with high processing speed, volume and quality of information will become a key competitive advantage in the future. Therefore, at an early stage of planning of the ECH-Earth project, when assessing its investment attractiveness and developing a united digital economic model, the framework for the Big Data technology was developed to ensure project's competitiveness and possibility to scale it beyond the Earth environment to the near-Earth orbit. In this context, the amount of collected and processed information, as well as data processing speed for decision making processes are of the high importance.

The authors thoroughly reviewed literature on Big Data processing technology for finance evaluation processes versus traditional evaluation approaches, with results summarised in section 18.2 in a comparison table. The authors paid much attention to drafting the methodology for the core processes of building a united digital economic model based on Big Data technology, which is presented in section 18.3. This section also lists the major benefi s of the proposed approach. Section 18.4 highlights the main conclusions and directions for further research.

18.2 Literature Review

Currently, a large variety of economic methods exist to assess investment attractiveness of infrastructure projects. The existing approaches are based on a scenario, where a set of initial data and necessary calculation equations are available, the calculations themselves are made, conclusions on investment attractiveness of the considered facility have been drawn. Examples of using such methods are:

- NPV-at-Risk assessment, which combines the weighted average cost of capital and dual risk-return methods [9], and it was made based on the construction of the plant;
- method to evaluate the net present value (NPV), internal rate of return (IRR), return on investment (ROI) based on the appraisal of the energy infrastructure investments [10], considering the specifics of the projects

- a methodology for multicriteria economic analysis of the effectiveness of mega transport infrastructure projects, to complement NPV evaluation with a framework of goals and a balance approach [11];
- NPV method using a static and dynamic approach, explored by reference to the illustrative examples and showing the benefits of each o them [12];
- discounted cash flow method and sensitivity analysis when measuring the company's market value [13].

Evolution of Big Data technology, especially with application to the financial sector [8], transforms the approach to the development of economic models. Without changing the framework of assessing the investment attractiveness of projects, Big Data technology particularly affects the process of Big Data collecting and processing, as well as visual presenting of the outcomes.

According to the authors [8], leading financial institutions and companies are actively introducing advanced Big Data technologies in their daily operation. Using various innovations, they get useful information from the data array, organise it, reduce the response time for decision making processes, improve the scalability of the algorithms, refine the models and data structures to create new business architectures. This major transformation of the approach in the area of financ also has affected the issues of assessing the investment attractiveness of projects, thus allowing managing a facility with a focus on the market value growth of the assets.

Nowadays, applying of Big Data technology has been widely discussed in publications of the scholars and industry practitioners worldwide. Over the time, the subject has been increasing its importance due to the following factors: growth of the volume of available data [14] and the increasing number of data sources [15], advancements in data collection technologies and innovative approaches in its processing [16]. At the same time, these trends have also affected the area of financial management [17].

According to the existing research papers, there are two key trends affectin the area of financial management, which are the growing size of companies and advances in information technology [18]. Herewith, the functions of the area of financial management have been extended

Besides such functions as planning, organising, control, motivation, adaptation, coordination, forecasting [19], new specific opportunities are formed, for example, managing the company's added value [20], including the use of information technologies. Existing examples are based on the dedicated computer programs for effi ent information processing and describe the approach aimed at assessment and increase of the company's value using repeated planning cycles [21, 22].

Since advances in Big Data technology allow considering multiple factors of the external and internal environments, another new function of financial management can be identified in the monitoring of signals received from databases in order to generate new knowledge about the object, thus allowing developing more sophisticated business models [18].

Using Big Data technology in the infrastructure projects, specifically for ECH-Earth, allows fulfilling major financial management functions and expand functionalities in areas such as:

- assessment of investment attractiveness of ECH-Earth facilities;
- management of the market value of a single facility or a network of similar facilities globally;
- informed decision making process based on the analysis of factors of external and internal environments;
- visual demonstration of the processes related to the facility, including assessment of the impact of such processes on economic indicators.

It is necessary to mention that during development of a unified economic model to replicate ECH-Earth facility, the following indicators should be evaluated: key factors aff cting the market value of assets and the figur s resulting from the investment appraisal. These factors may be linked to their relevant drivers of the value growth, which, in return, have a great impact on the investment attractiveness of ECH-Earth, thus increasing the capitalization of the facility [7].

Using Big Data technology is complementary to the traditional approach in assessing the investment attractiveness of infrastructure projects, which is based on calculating NVP values [23].

However, it is possible to identify the key differences between Big Data technology in financial management at the stage of assessing the project's investment attractiveness and further function of company's value management, and traditional assessment approaches. Comparison between these ideas are summarised in Table 1.

Table 1 – Comparative assessment of the traditional approach to defining investment attractiveness of the project and method using Big Data technolog

Comparison parameter	Traditional approach	Big Data approach
1	2	3
Risk assessment and management technology	Uses pre-determined coefficients (secondary data) [2	Uses collected initial data thereby reducing the risk of uncertainty of owning the assets [18]
Scenario planning	Is based on probability distribution and possible scenario evaluations [25]. Monte Carlo method is usually used [26]	Scenario planning is based on the system of Big Data analysis that allows automatic planning of market scenarios using digital platform. Scenario planning methodology is based on prescriptive analytics that involves generating of business scenarios and their optimisation [27]
Interdisciplinary interaction in initial data formation	Is limited by factors and data obtained from external and internal sources, typical for the market processes [28]	Allows complementing market factors with the data obtained from physical objects (cyber-physical systems) thus increasing the accuracy of data to make decisions [14]

The end of Table 1

1	2	3
Calculated parameters	Allows calculating key figures to assess the project's investment attractiveness, such as NPV, IRR, ROI, PI, limited by the known equations without relation to the data collected [29]	Allows to obtain complex analytics using parameters and values available in the data base or establishing links between them [17]
Approach to data collection to build an assessment model and further use of the assessment model	Assessment data are delayed, distorted, and have certain errors [30]	Very fast data collection allows making well-balanced strategic choices [31]
Probability and accuracy of forecasts	Estimates are less accurate since limited number of factors are evaluated [32]	Using Big Data technology helps improving forecasts through evaluation of the hidden patterns [33]
Model's function for value management	Managing the company's value involves the function of assessing its current value that is used for mergers, acquisitions, sale, purchase of assets, contributions to the authorized capital and measuring the impact of value changing risks [34]	The model becomes a tool to both assess the value of the company and to increase its value, identify possible scenarios and assess the value of the company in the future. The model considers external and internal factors affecting th "company's market value" parameter, thus ensuring a 360-degree view of the evaluated object [8]
Data continuity	At the time of obtaining assessment results, initial data may change, which misrepresents the outcome. The achieved results then will become only the model with represented linkages between the figure	Due to fast data collection and processing, the delay in updating initial data is minimal, thus reliability of the outcome has a smaller error [33]
Technology used to calculate the model	Mainly standard Microsoft Offic packages or specialized software (COMFAR 2.1, Project Expert Alt-Invest, etc.) are used	Allows using financial modeling technolog such as: data visualisation using Power BI technology [35], scenario planning using quantum technologies [36], data storage, and processing using cloud technologies [37]

Both approaches compared above (Table 1) demonstrate similarities typical for traditional technologies used to assess the project's investment attractiveness (calculating economic indicators (NVP, IRR); methods used for scenario planning, such as Monte Carlo method), and unique aspects attributable to Big Data technology in financial management. This combines multiple factor analysis; linkage with physical objects; faster data collection and processing; decision making using Artificial Intelligence trained with Big Data

Evolution of Big Data technologies has changed approaches to decision making by shifting them towards continuous cyclic data processing, assessment of preselected parameters, which allows using these technologies to manage company's value as well.

18.3 Developed Approach Description

The united digital economic model is a set of values that describe physical processes of the company's activities recorded as data array. It allows to assess the project's NPV at the planning stage and during its implementation, as well as predict changes of the company's value based on discounted cash flows (DCF model) [34].

The new approach allows evaluating economic variables, including the "company's market value" parameter, which was calculated based on DCF model (initially, without considering the size of the issued stocks and its market price), by collecting two types of data [34]. The first one is data collected from commercial activities when managing the facility. The second one is data from monitoring existing processes or physical phenomena inside or outside the facility, such as changes in electricity consumption or its market price flu tuations. Both types of information are recorded into the relevant structure. The data is then processed using Big Data technology and based on that careful managerial decisions are made. The model is included into the approach to assessing the investment attractiveness of ECH-Earth, which is based on multi factor analysis [38].

When elaborating a united digital economic model, six core factors were considered that have the highest significance for the outcome of the project investment attractiveness estimation:

- market reachability matrix [39] and the revenue model that are based on project estimation results;
- assessment of potential investments under key structural design solutions (CAPEX model);
- assessment of potential operating costs under main expenditure items (OPEX model);
- basic taxes and related budget payments set for the model without reference to a specific countr , which need to be adjusted for a specific location
- assessment of risks and discount rates calculated using WACC formula [40];
- planning timeframe for the construction and launch of the facility.

A united digital economic model was built using the example of the structural design concept of a torus section 30 m in height, being the most appropriate shape for ECH-Earth purpose [1]. Development of the model included four stages, as discussed below.

Stage 1 involved collecting of the initial data on the expected physical processes and phenomena that will occur in ECH-Earth, taking into account the requirements for their creation and maintenance. The data was collected and arranged in such a way that it was possible to build a continuous dynamic series of values.

Initial data for the ECH-Earth facility was collected based on six key factors that form a single conceptual solution [7]. Basic groups of factors (and their parameters) that have the highest influence on the projected market value of the entire facility are shown in Table 2.

Table 2 demonstrates the major possible factors (and also their characteristic parameters) that have the most impact on projected cost of business, which reflects the investment attractiveness of the entire ECH-Earth.

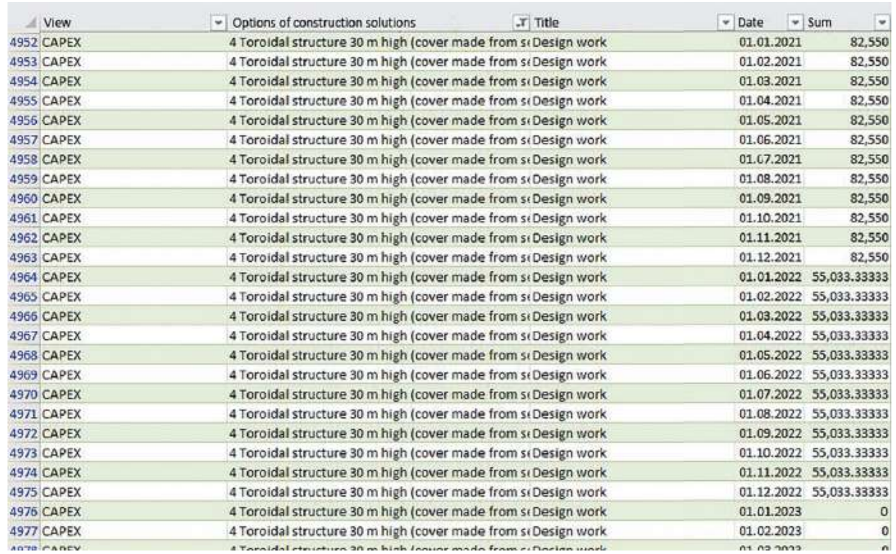
Table 2 – Groups of factors that have the highest impact on ECH-Earth market value

Groups of factors affecting the company s market value	Value
1st group of factors. Tourism and hotels	
Number of double rooms, units	180
Average room price at ECH-Earth per night, USD	100
Average room price at ECH-Earth per night, USD	60
Number of staff, peopl	107
2nd group of factors. Biosphere and farming	
Green area inside ECH-Earth, m^2	17,574
Total weight of soil layer inside ECH-Earth, tons	Over 50,000
Total weight of living fertile humus inside ECH-Earth, tons	Over 300
Total crops inside ECH-Earth, units	Over 100
Total animal species (including birds and fish) inside ECH-Earth units	Over 100
Number of staff, peopl	26
3rd group of factors. Leisure and recreation facilities	
Number of additional paid services, conv. units	34
Average bill per person for other services per day, USD	90
Area for recreational facilities inside ECH-Earth, m^2	5,060
4th group of factors. Feasibility of the enclosed ecosystem	
Area of the building, m^2	21,500
Volume of the building, m^3	316,200
External surface area, m^2	28,000
5th group of factors. Adjustment of the facility to the environment	
Area under solar panels, m^2	At least 2,000
Optimum temperature range inside ECH-Earth, °C	20–25
Annual oxygen need for an average person, kg	250
6th group of factors. R&D	
Number of residents inside ECH-Earth, people	100
Share of R&D spending in total investments, %	20

Stage 2 involved data processing tools to prepare further analysis of the information. Stage 2 resulted in a lengthy list with more than 100,000 economic values collected during the initial stage of planning. Figure 1 shows an example of the database.

Stage 3 was the processing of the data array and generating of a united digital economic model recorded for nine design options. Figure 2 shows an example of a generated model.

A model is a set of related data formed into a single table with relevant sections.



	View	Options of construction solutions	Title	Date	Sum
4952	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.01.2021	82,550
4953	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.02.2021	82,550
4954	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.03.2021	82,550
4955	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.04.2021	82,550
4956	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.05.2021	82,550
4957	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.06.2021	82,550
4958	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.07.2021	82,550
4959	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.08.2021	82,550
4960	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.09.2021	82,550
4961	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.10.2021	82,550
4962	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.11.2021	82,550
4963	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.12.2021	82,550
4964	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.01.2022	55,033.33333
4965	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.02.2022	55,033.33333
4966	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.03.2022	55,033.33333
4967	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.04.2022	55,033.33333
4968	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.05.2022	55,033.33333
4969	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.06.2022	55,033.33333
4970	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.07.2022	55,033.33333
4971	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.08.2022	55,033.33333
4972	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.09.2022	55,033.33333
4973	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.10.2022	55,033.33333
4974	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.11.2022	55,033.33333
4975	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.12.2022	55,033.33333
4976	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.01.2023	0
4977	CAPEX	4 Toroidal structure 30 m high (cover made from s	Design work	01.02.2023	0

Figure 1 – Database with values of ECH-Earth

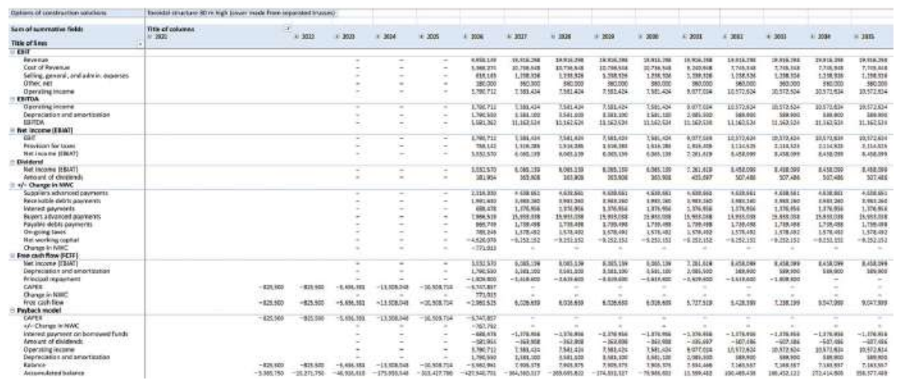


Figure 2 – United digital economic model representation

Stage 4 is a graphic representation of the outcome using Power BI information processing technology [35]. The outcome, presented in Figure 3, shows information about planned profit margin before interest, taxes, and depreciation (EBITDA) for nine design options.

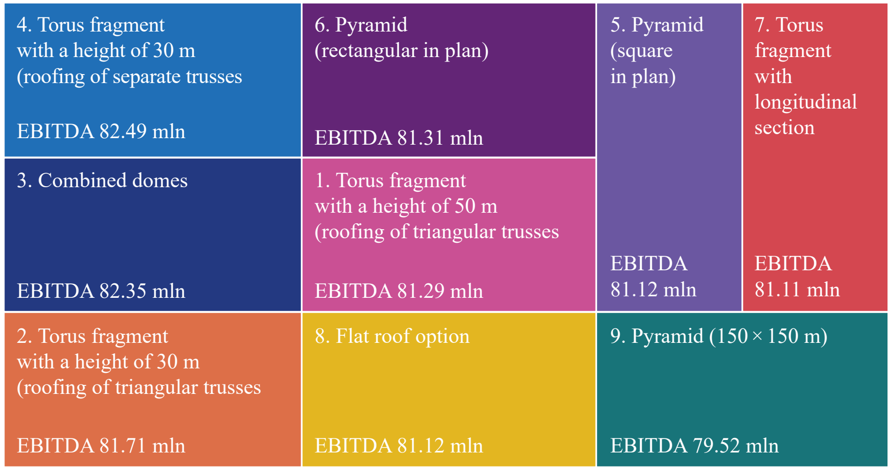


Figure 3 – EBITDA rendering for nine design options

Figure 3 shows that the design option with a 30-metre-high torus segment (top left sector) has the largest EBITDA value indicating that it is the best shape for ECH-Earth, including its investment attractiveness. This type of united digital economic model generated using Big Data processing technology enhances conventional tabular forms with modeling- and scenario planning-related approaches, integrating it with analytics and visualisation tools. Herewith, it allows generating targeted projected values obtained using a single digital economic model with traditional assessment methods, as it was summarised in Table 3.

Table 3 – ECH-Earth key performance indicators obtained using a united digital economic model through the example of 30-metre-high torus segment

Parameter	Value
Payback period (PP) from the commissioning of the facility, years	7.6
Payback Period (PP) from the start of design and first capital xpenditures, years	13.1
Discounted Payback Period (DPP) from the commissioning of the facility, years	9
Discounted Payback Period (DPP) from the start of design and fi st capital expenditures, years	14.5
Net Present Value (NPV), thousand USD	1,809.1
Internal rate of return (IRR), %	5.2
Profitability inde	1.05

This model allows to assess different design options simultaneously, it allows assessing various factors when replicating the facility, in particular, building a network of similar multi-purpose complexes worldwide. This model also enables a comparative assessment at the stage of project planning to choose the best solution. Detailed description of deliverables will be available in the business plan for ECH-Earth project with extensive indicators added.

The resulting united digital economic model provides the foundation for evaluating the ECH-Earth project which leads to the multi factor analysis.

Obtained data represents the planned values of economic activity of the ECH-Earth facility (the first type of data) and later they shall be supplemented and linked to the second type of data collected during monitoring of the facilities, physical processes and phenomena inside and outside ECH-Earth. Although benefits of introducing Big Data technology in ECH-Earth is hard to assess at the current stage of the project, since it requires deeper exploration of the internal systems of the facility and elements of complex analytics, it is possible to form principles to be proven when this technology is introduced in such facility.

These principles include:

- quick collection of data and their user-friendly representation;
- assessing changes of indicators after processing initial data;
- allowing plan-actual and function value analysis [41] according to the planned forecast values in the investment model of the project;
- assessing various behaviours of the systems within ECH-Earth since data collected is not ready-made, but rather represents an organised array of information. Herewith, managerial reporting may be represented with the relevant set of values to ensure informed managerial decision making.

Once these hypotheses are proved, this approach then may be applied to other multifunctional infrastructure facilities and not just to ECH-Earth, such as linear cities [42]. For such facilities, Big Data shall be collected and processed to assess and control economic functioning parameters.

18.4 Conclusions and Future Work

So far, the authors used only few Big Data technology principles relevant to assessing investment attractiveness of the ECH-Earth facility.

Generated model allows using it in two applications: evaluation of investment attractiveness of a project at its early planning stage and management of the facility in the future for strategic decision making, including through modeling various project implementation scenarios by regrouping and adding data, generating various types of reports and their immediate analysis based on complex event processing.

The approach suggested by the authors allows structuring economic data as an array of information about a facility thus taking into account the influ nce of a large amount of factors, their further real-time collection from various types of data sources during functioning of ECH-Earth.

Suggested united digital economic model is one of possible applications of Big Data technology in financial management. It allows both to use Big Data technology and address deliverables visualisation issue based on BI technology as an example [35], and it allows to attract further financing and manage the market value of the facility in the future.

Linking physical phenomena to their economic assessment allows to consider ECH-Earth, which is a scientifi experiment, from investment and further capitalization perspective, and replicate the facility worldwide.

This approach is assumed to allow other companies to use traditional ways to attract investments for the projects, such as bank loans, financing by investment funds, public offering of company shares in the market, and new instruments available in the fi ancial market, such as issuing tokens using digital platforms. This approach creates conditions for the company to disclose public fi ancial statements, actions taken, and expected financial results, and thus increase the market value of the facility. This approach also allows assessing application of various algorithmic strategies in company's operations management.

This topic will further be researched as follows:

- design of business processes for Big Data collection and processing based on links between physical phenomena projected for ECH-Earth and economic indicators of functioning of the facility;
- development of tools to collect Big Data from infrastructure facilities and other objects following the example of ECH-Earth together with assessment of their impact on projected economic parameters;
- implementation of a corporate information system to manage Big Data for the purposes of financial modeling and to manage the market value of the facility;
- searching for solutions to integrate a single digital economic model with Blockchain technology, Artificial Intelligence, Quantum Data Encryption

Application of the approach covered in this paper will allow to come up with the strategies to increase the market value of the facility (enterprise value indicator [43]) and its investment attractiveness for investors and shareholders.

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19

EcoCosmoHouse Biosphere Key Elements: Integrations, Interactions, and Diversity Support

19.1 EcoCosmoHouse as a Space for Conservation of Tropical and Subtropical Flora Diversity

Nowadays, issues of conservation and rational use of natural resources, including plants, have hit the mainstream. Biological diversity is a basis for the necessary environmental conditions and steady economic growth of the society. There is an obvious need in development and implementation of effe tive measures to preserve plants' biodiversity worldwide. In N. Pitman and P. Jørgensen's study, it was calculated that about 94,000–193,000 plants' species are under threat of extinction out of totally recognized 300,000–420,000 species worldwide [1].

Studies of tropical plants are necessary to understand the paths and laws of Earth's plant world evolution. Plant growing in tropical areas provides a variety of healthful and essential products: bananas, pineapples, vanilla, black pepper, coff e, and cocoa. Furthermore, large amount of raw materials for medical and aromatic substances are produced in tropical countries. One of the key goals of the Global Strategy for Plant Conservation is to save economically valuable botanical species used for food, textile, aromatic, and medical purposes [2]. The concept of the EcoCosmoHouse (ECH) is based on modeling of tropical and subtropical environmental conditions as close as possible [3]. Such conditions allow to receive products all year round and grow different types of plants. Moreover, these plants' species will provide convenient living conditions for ECH residents.

Through creating a variety of flor within ECH, the optimal conditions for enclosed ecosystem development will be provided, as well as a foundation to solve a number of environmental issues will be prepared and a good collection of plants will be formed. Subsequently, it will be possible to reintroduce rare and extinct species into anthropogenically modified biotopes, as well as to develop a range of topical species used for modern urban greening.

The core function of plants in ECH is oxygen production and carbon dioxide processing. Plantings will ensure maximum autonomy of ECH residents regarding food, medicines, and other resources. Another significant function is creation of convenient conditions for the residents. Composition of plants should be harmonious and aesthetically acceptable, therefore, ECH's plants layout may be supplemented with decorative-leafy and blossoming plants such as pitaya, dragon fruit *Hylocereus undatus*, *Canna L.*, *Chionodoxa boiss*, nomadic *Athyrium roth*, etc.

The flora of Belarus includes about 4,100 species of higher plants [4]. In recent years, a special focus was on the problem of biological diversity and its conservation. It is known that in order to preserve and restore rare plant species they have to be introduced into botanical gardens. The Central Botanical Garden of the Belarussian National Academy of Sciences is a near-single entity in Belarus that conducts real bioecological studies of rare and protected plant species.

EcoCosmoHouse on Planet Earth (ECH-Earth) may become the second (but not regarding its value) facility to preserve plants biodiversity with the area of about 2 ha. A series of research tests conducted in the ECH-Earth in Belarus will assess the possibility to spread the biological diversity in colonies placed on the near-Earth orbits.

Considering all the above factors, creation of the ECH should be based on the natural technologies or some solutions close to them. Many natural processes can be accelerated with the use of modern equipment, for example, formation of humus. The right proportion of high-quality humus in the soil is essential to maintain the flora biodiversity. Such combination accumulates a large number of macro- and microelements, growth substances, and vitamins that are directly absorbed by the plants. Nature and speed of humus formation depends on a number of factors, among which are the soil profile structure, humidity, and aeration conditions, composition of the microflora and its activity. Thus, creation of an optimal soil composition and formation of humus are the key points for growing tropical and subtropical plants.

It is important to prepare a soil profile with the average depth of 1.3 m for a comfortable growth of woody plants in ECH-Earth. In the upper layer of 0.3 m, it is permissible to use humus from brown coal together with biohumus. It is worth noting that concentration of humus will vary throughout the ECH-Earth's area. Soil profile will be different in the areas where the ground is molded over the bare foundation or in the zones of streams and lakes.

Indigenous soil may be used in ECH. It should be taken into account that heavy unstructured soil in the composition of turf soil (more than 50 %) may result in water stagnation in the soil upper layers. Consequently, water will not come to the adult trees root. Thus, it will be necessary to put structured soil separately for each plant.

One of the proposed options for the bulk soil includes structured soil consisting of the following horizons: top layer of fertile soil with a high concentration of microorganisms (humus with the thickness of 30 cm), eluvial horizon (sod ground, 40 cm), illuvial horizon (sandy loam mixed with crushed brown coal, 45 cm), and a drainage layer (crushed stone, 15 cm; sand, 15 cm). The fertile top layer consists of humus, biohumus, transitional and lowland peat, and sod ground.

Back in the 60s of the last century, it was proven that introduction of brown coal into the soil leads to increased crop yields [5]. Brown coal has high concentration of humic substances and, potentially, it is possible to produce a quite high-quality fertiliser on the base of coal, especially in combination with nutrients from various types of organic raw materials (i.e., biohumus) [6].

The current project proposes to mix biohumus with humus from brown coal. Test results revealed that biohumus from brown coal contains the maximum number of microorganisms assimilating mineral forms of nitrogen which exceeds the control values calculated for the substrate without vermicomposting by 128 %. Biohumus derived from cattle's straw-based manure, contains the highest amount of ammonifying bacteria with its concentration of 5.96×10^9 CFU/g. The developed solution regarding soil composition may also include the use of general biohumus.

A quantitative method to count viable cells in substrate samples is used to estimate concentration of microorganisms [7]. Consideration of the main ecological and trophic groups was carried out by seeding on agar media. Mass fraction of the following elements was determined according to the relevant standards: total nitrogen – GOST 26715-85, clause 1, phosphorus – GOST 26717-85, potassium – GOST 26718-85 [8]. The content of humic substances was estimated according to the standard STB 2392-2014, clause 5.7 [9].

Historically, the use of liquid biohumus has evolved from such horticultural practices as soaking of manure or some plants. Achieved liquids were used as fertilisers and treatment for leaves against diseases and pests.

Tests of liquid biohumus revealed a high content of humic substances (more than 60 %), as well as general forms of nitrogen, phosphorus, and potassium (5.1 %, 3.8 %, 9.6 %, respectively). On this basis, liquid biohumus diluted in water is proposed to be used for plant nutrition and leaves processing.

The results of biohumus testing confirmed the importance of its use in the soils composition within ECH's territories; liquid biohumus plays the key role in plants processing and nutrition. In the course of modeling of plant species diversity for ECH-Earth conditions, it is necessary to take into account the minimum set of factors, such as lightness, soil selection, temperature, and humidity (of air and soil).

To conclude, when solving the problem of biodiversity conservation on Earth, EcoCosmoHouse can serve as an alternative solution to the specially protected natural territories, which are influenced, undoubtedly, by external factors and climate changes. In addition, ECH (due to creation of an optimal soil structure) may be the first facility to preserve flora biodiversity outside Eart

19.2 Trophic Chains and Biological Rhythms as Basis for Creation of EcoCosmoHouse Biosphere

Biosphere of EcoCosmoHouse is defined as an enclosed area that includes many communities of living organisms. They are capable of self-reproduction and full-value existence for infinite period once the required combination of abiotic factors is provided. On the one hand, this is an artificial ecosystem, as it will be created by an engineer, on the other hand it is natural, since all living organisms will be delivered from planet Earth without any changes (including genetic modification) being originated from the terrestrial biosphere, which came through billions years of evolution. Since the entire biosphere cannot be recreated in ECH, it will be artific al only with regard to simplification and localisation of the recreated model. At the same time, an enclosed local ecosystem is a rather narrow concept that includes separate biosystems consisting of communities of living organisms from different habitats. Furthermore, it includes their systems of established trophic relationships that exchange substances, energy, and information.

Designing of enclosed artificial ecosystems is one of the most urgent problems of humankind. Firstly, space era dictates this problem [10–12]. Secondly, the issue comes from the need of restoration and development of the ecosystems, that requires understanding of the entire complex of biological processes to create a new model [3].

In connection with the above, the purpose of this work is to build a model of homeostasis regulation of EcoCosmoHouse local artific al biosphere subject to trophic relationships and biological rhythms.

The most well-known large-scale projects in the field are BIOS-3 [13, 14] and Biosphere-2 [15, 16]. Implementation of these projects allowed to obtain colossal amount of data. Its analysis indicated a number of challenges regarding existence of biological organisms within an enclosed localised biosphere. At the same time, this experience provided a foundation for modeling of small artificial ecosystems (for example, EcoSphere Closed Ecosystems, AquaWorld, Eternal Terrarium closed ecosystems, etc.), showing their viability for 2–15 years (scientific experiments on this subject are almost absent).

A good example of an accidental creation of an artificial ecosystem is the experiment of the electrical engineer from Cranleigh (Surrey, UK) – D. Latimer. In 1960, he, out of curiosity, planted four seedlings of tradescantia into a huge glass bottle and closed it. Only one plant survived, but it formed a mini ecosystem that has existed for about 60 years [17]. Considering this example, the following can be observed. Water, in the enclosed system of the glass jar, evaporates from the surface of the soil and plants and, later on, condenses on the walls. It allows watering the plants. Oxygen, which was produced in an enclosed system, was absorbed during rotting of fallen leaves. The formed carbon dioxide was reintegrated into the process of photosynthesis. Consequently, such small ecosystems can serve as examples of a practical approach to developing mechanisms for maintaining viability of the artificial ecosystems

Modelling of artifici l ecosystems is based on establishment of homeostasis at all levels of living organisms' communities' organisation, considering the regulation of abiotic and biotic factors. At the same time, it is important to use the concepts of trophic chains and biological rhythms. Stability of the corresponding biocenosis processes depends directly on organisation of the trophic structure of living organisms' communities with regard to its seasonal rhythmic.

The trophic (food) chain means transfer of substances and energy from autotrophs to heterotrophs, that occurs because some organisms consume others [18]. That is why the trophic structure within EcoCosmoHouse [3], which we consider as a cycle (Figure 1), is of particular importance. This approach provides understanding of the role of each biological component in the artificial ecosystem structure.

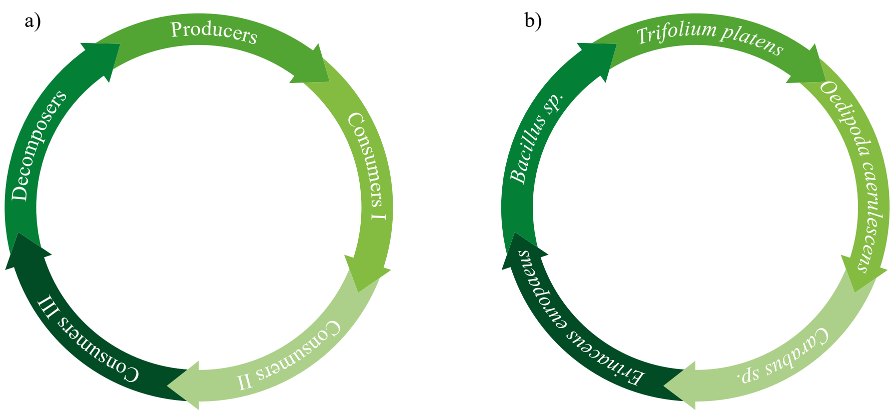

Figure 1 – Trophic cycle with indication of the corresponding trophic level:
a – trophic cycle with indication of trophic levels; b – a specific example of the trophic cycl

However, trophic cycles should be the foundation for an appropriate energy balance. About 10 % of the energy remains in the process of its movement from the more energy-intensive level to the next one from producers to decomposers (R. Lindeman rule) [19]. To figure the trophic structure of a biocenosis, the pyramid model [20] is used (Figure 2). It can reflect the number of individuals (a pyramid of numbers), their biomass (biomass pyramid) or energy contained in it (energy pyramid).

To understand the entire structure of interactions in trophic chains, it is proposed to use the trophic networks (Figure 3), which would include the nutritional relationships between a number of organisms. In food networks, the following types of links are distinguished: permanent, temporary, random, and hypothetically possible. Permanent relationship is a relationship that occurs with high frequency or exists permanently (for example, the relationship of monophagous). Temporary relationship is a relationship formed under certain conditions (for example, during outbreaks of mass reproduction).

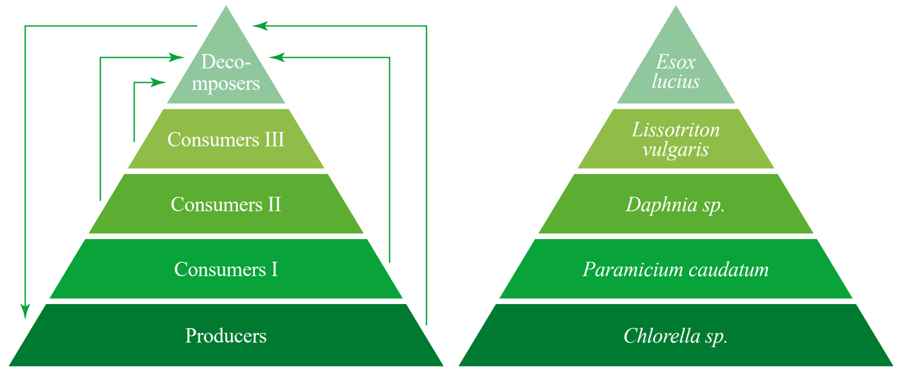

Figure 2 – Biomass pyramid

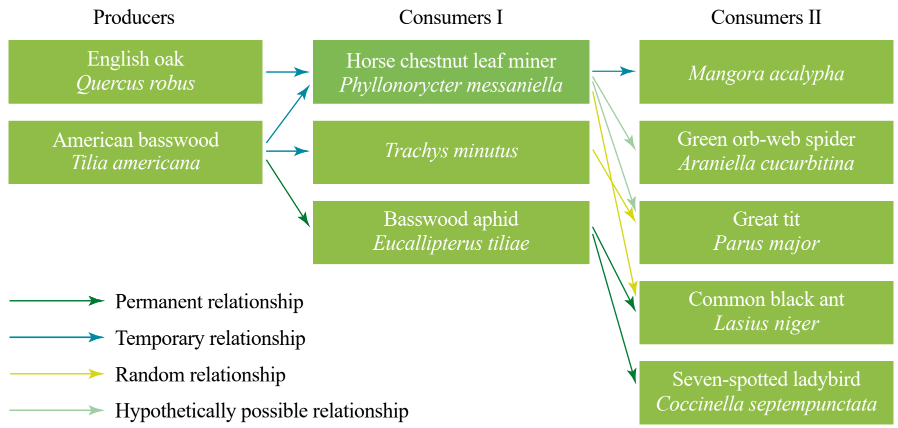

Figure 3 – Fragment of ECH trophic network

Random relationship is a very rare relationship, having a random nature. A hypothetically possible relationship is the alleged emergence of a relationship based on the trophic level, behaviour and trophic preferences.

Model of the trophic network has gradually expanded due to the growing number of the organisms, included in ECH. It requires to decrease complexity and unify the network to a single model that will be able to reflect the communities of living organisms. In this regard, the authors propose an innovative model of regulating homeostasis within the artificial biosphere with the use of multi-level dynamic network that being filled graduall , will take a spherical shape (Figure 4).

Authors introduced the following set of rules to ensure the model proper functioning: each species of living organisms is included into the model only once; each class of biological organisms can have an infinite number of food links, but not less than one; relationships in the model can be vertical and horizontal;

Figure 4 – Multi-level dynamic network model of homeostasis regulation of the artificial biospher

when creating a network, it is necessary to take into account the nature of interrelationships between the ecosystem biological elements (permanent, temporary, random, and hypothetically possible ones); possible dynamic transition of any organism to any of the trophic levels due to the change of the trophic level of a particular food chain, etc. It worth to mention, the wider the network and the more accurately the nature of the interconnections in the multi-level dynamic network model for controlling the artificial biosphere homeostasis are indicated, the more qualitative evaluation results can be obtained; possible dynamic transition of any organism to any of the trophic levels due to the change in the trophic level for a specifi food chain, etc.

The proposed model founded on trophic levels and relationships is a database of a number of biotic and abiotic indicators. Filling procedure should comply with the following scheme: the name of a living organism, the trophic level(s), the trophic relationship(s), phenology, information about biorhythmology features, amount of food consumed, gas exchange, methods for identification and possible ways to regulate the total number, etc.

Such a model will become a basis for understanding the entire system of relationships between living organisms, and also serve as a tool helping to understand the flow of all energy processes taking into account abiotic factors. It will allow calculating a specific number of organisms in ECH that previously was calculated with a very low accuracy. The death of certain types of organisms, significant reduction or rapid population growth of the elements in the trophic network can lead to catastrophic consequences. However, by having such a full-fledged model, it is possible to regulate, as well as determine various ways to solve the problem, it means that violations of the biospheric homeostasis can be solved instantly. In addition, the framework of the model includes a biorhythmology of living organisms. Biological rhythms are periodically recurring changes of biological processes intensity and their nature [21]. In some cases, biorhythmology leads to a change in nutrition of living organisms. In this regard, biorhythms can also be considered as a part

of the proposed model forming a highly sensitive tool to create a highly efficien enclosed ecosystem. Software platform is the best way to implement the described model subject to the majority of the elements indicated above.

The main problem of this approach is low understanding of the specific trophic relationships and biorhythms of individual organisms besides availability of a number of advanced studies. Collection of the information regarding ecosystems' balance is still in process. In addition, new species of living organisms are being found and described annually. These species also occupy a certain place in the established biological systems. One of the complications is transition of minor and/or additional relationships into fundamental group of relationships within the artificially created set of conditions. Moreover, new connections may arise, that may lead to destabilization of the developed scheme of interaction between living organisms. All this should be maximally investigated and structured on the basis of the proposed model. Subsequently, this approach will allow to perform transformation of the ecosystem and control its development.

Considering the biological structure of ECH, it is necessary to take into account the fact that live fertile soil is the basis of life and the immune system of any biosphere. The soil has to be transferred unchanged, i.e., live soil from planet Earth with thousands of species of microorganisms, about a trillion individuals per 1 kg of soil. To create ECH local biosphere, it is planned to include more than 2,500 species of plant organisms (more than 2 mln individuals), over 4,000 species of animal organisms (about 2.5 mln individuals). At the same time, the microflora and microfauna of soil and aquatic environments will occupy a central place among transferred living species.

To arrange proper supply of nutrients in ECH, it is necessary to provide about 1,000 m^2 of soil surface per person, whereof (approximately) 10 % will be used for oxygen production (taking into account the use of chlorella), 50 % – for plant foods (vegetables, fruits, herbs, grains, etc.), 40 % – for animal foods (meat, milk, cheese, etc.) However, with the use of advanced technologies and processes optimisation, it is possible to reduce required soil area by two times or more. To product food amount sufficien for full nutrition of one person, the following number of farm animals should be maintained in ECH (approximately): 1/50 of a cow, 1/20 of a goat, 1/10 of a pig, 1/10 of a lamb, 1/30 of a bee colony, five quails, two hens. In addition, the optimal need for fruits, herbs, and fish will be provided with the following specific indicators (in terms of one person) for trees, shrubs, garden beds, water surface (approximately): 1/2 of an apple tree, 1/2 of a pear tree, 1/2 of a peach tree, 1/2 of an apricot tree, 1.2 of a plum tree, 2 m^2 of parsley and dill, 10 m^2 of microgreens, 10 m^2 of fresh water, etc. (Figure 5).

Thus, inclusion of the trophic relationships and biorhythms is an integral part of the enclosed biosphere creation. Having reviewed some quantitative data on the number of living organisms in the EcoCosmoHouse, it is possible to conclude that the proposed model with multi-level dynamic network to control homeostasis of the artifi ial biosphere solves the problem of structuring and managing the enclosed ecosystems.

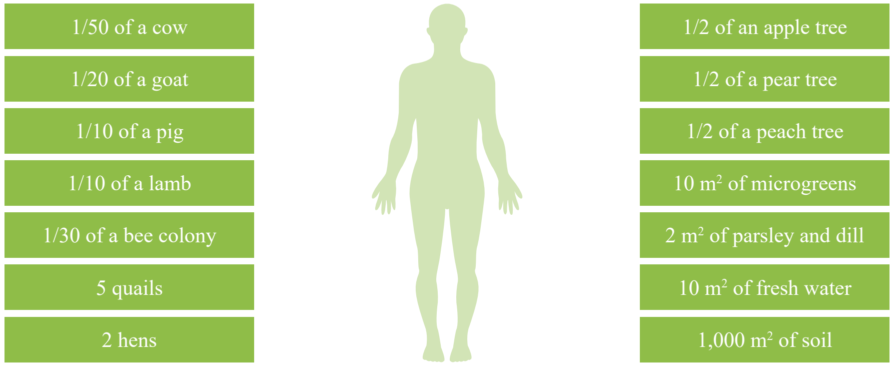

Figure 5 – Diagram of some food elements necessary for the full existence of one person in ECH

19.3 Ways of Adaptation and Establishment of Enclosed Ecosystem Autoregulation

One of the most acute problems of our time is the growing environmental global crisis [22]. Environmental problems are becoming more serious because the technosphere has a negative impact on the environment as a result of its energy demands [3]. The only way to conserve biodiversity and reduce the impact of this technocratic civilization is to transfer harmful industries into Earth's orbit and industrialize near space. Permanent comfortable living process in space requires formation of conditions similar to earthy ones. It can be recreated within an enclosed ecosystem.

This paper observes modeling of an enclosed ecosystem for its further implementation in EcoCosmoHouse on Planet Earth which is a prototype of EcoCosmoHouse space settlement [3].

All living organisms in the biosphere interact with one another and are influence by abiotic environmental factors [23]. There are a lot of different enclosed ecosystem rules based on the principle of energy conservation and its transmission to other living organisms [24]. One of the main problems during modeling of enclosed ecosystems is establishment of stable cycles of organic substances and data exchange, including genetic information. Adaptation of living organisms and gradual balancing of the system take place through these processes in an isolated environment.

This research studies the adaptive processes of the population through creating trophic paths in an enclosed environment. According to the aim of the research we designed an enclosed ecosystem installation, studied the interaction between living organisms and their development, and analysed interactions between living objects.

In subsection A, issues and solutions regarding the main processes in enclosed ecosystems and adaptive interactions are reported. In subsection B, the experiments and the developed set up are described. In subsection C, the research methods are specifi d. In subsection D, we present the results, discuss them, and compare our

findings with those found in the literature. In subsection E, the project's conclusions and suggested possible topics for future research activities are stated.

A. Main Stages of Natural Ecosystems Formation

Interaction of all living organisms is the basis of biocenosis in an enclosed ecosystem. Any existing ecosystem has to come through the main stages: birth, adulthood, youth, old age [25]. Environmental processes start and stop at fixed intervals [26]. For example, soil formation on Earth. Microorganisms appear on the parent rock (rock, stones, etc.) at the beginning of the ecological succession [27, 28]. Some scientists suggest [25–28], that these organisms are archaebacterial in nature. They are able to synthesize organic matter through chemosynthesis. Further on, the nutrient base is formed by algae and plants [29]. Accumulation of organic matter leads to formation of the "primary soil" [27]. The simplest animals appear and their waste products enter the soil and participate in formation of humus. Then, highly organised plants and animals appear in the ecosystem. It leads to the ecosystem climax [24]. Then, self-renewing of the old ecosystem is possible. Self-renewing of the ecosystem means occurring of new evolutionary forms of living organisms that are able to adapt to a new environment [30]. These processes take decades to complete, so it is important to control the elements circulating within the ecosystem and population dynamics using artificial regulation of individual living o ganisms [29].

According to the environmental studies, proper functioning of the enclosed system requires to establish energy cycles and elements transfer from one organism to another [23]. So, according to M. Saltykov's publications [24], the study of an ecosystem using only trophic chains of energy transmission and movement of matter through an enclosed system, it is hardly possible to predict development of such an ecosystem. Therefore, additional laboratory indicators of animal and plant behaviour should also be considered. For instance, under the influence of stress factors (high humidity, high or low temperature, intraspecific conflicts etc.) some individuals of even species may start eating nontypical elements that weren't considered in the trophic chain [29].

For example the trophic chain consists of two types of producers (*Volvox*, *Diatoms*) and one primary consumer (*Daphnia pulex)*. In an artificially lighted aquarium the consumer eats the producers in equal measures. Then daphnia starts to actively consume *Volvox*. According to this process energy and matter accumulate inside *Daphnia pulex* and its number increases. If this situation is over a long period of time, the ecosystem becomes unstable. In this case, diatom algae and daphnia are growing at a huge rate, and the volvox population is disappearing [23].

In most cases, one of the main problems of enclosed ecosystems is rapid growth of primary consumers that leads to reduction of producers, thereof, it is required to control total number of all individuals within the populations [26]. Elimination of some populations and growth of others exclude stable existence of the ecosystem [27]. Diffe - ent variants of trophic chains should be considered during the stage of ecosystem design.

The difficultie in modeling of the enclosed ecosystems are always related to populations adaptation and their relationships. Creators of enclosed ecosystems rarely monitored trophic pathways and process of organisms' adaptation to new conditions. To model enclosed ecosystem an empiric approach (i.e., trial and error method) is used [29]. With this approach a large number of different living organisms don't connect with each other by trophic chains. That is why many living organisms are placed into struggle for resources to exist. This process leads to biodiversity loss within the ecosystem, thus disrupting circulation of chemical elements and living substance.

To solve such problems, it is necessary to consider different variants of trophic chains, that can be a new unit in feeding relationships. Different species have their own peculiarities in adaptation processes. Plants of the same ecological group complete different adaptation processes under equal conditions [31]. The main characteristic of plant biomass growth is presence of leaves, shoots, and root mass [32]. Animals go through the similar processes, but their indexes are body growth for up to adults excluding deaths of young animals [25].

Another thing which should be considered is dynamics of population represented by the constant number of individuals. This value may vary by ±10 % [29]. The positive percentage includes survived and young individuals, and the negative percentage includes dead ones. Because of stress factors in the ecosystem adaptation process there may be a decline of the individuals' number. It's directly related to abiotic or biological factors (parasitism, pathogen growth) [33].

Abiotic factors also play an important role in the adaptation process. For example, excessive humidity can have a negative impact on plants and animals and result in development of pathogens slowing down the system adaptation process [34]. Light in the enclosed ecosystem ensures synthesis of organic substances and regulate biological rhythms. The light wavelength should be maximally similar to the natural illumination and have a length range of 430–780 nm [32]. In addition, at the beginning of the ecosystem adaptation, the pH of the water system should be artificially maintained. A sudden change in water acidity may cause death of organisms or disable their physiological processes [33].

The most successful previous global experiences of operating with the enclosed ecosystems are Biosphere-2, BIOS-3, Yuegong-1, but their key problem lies in lack of consideration regarding circulation of all substances in the system. The projects were based on the complete reconstruction of Earth biosphere and isolated division of the system into natural biomes. However, the scale didn't allow to monitor all bioprocesses, that resulted in excessive amount of CO_2, lack of oxygen, and other problems. Thereby, before modeling a large biogeocenosis, it is necessary to analyse potential problems relating to the system balance.

B. Experiment Description

Description of the Isolated Enclosed Ecosystem Installation

An 80-litre aquarium was filled on 1/3 of its volume with water, stones, and ground. There were plastic partitions installed inside of it in order to separate and keep the ground from mixing with water components (Figure 6).

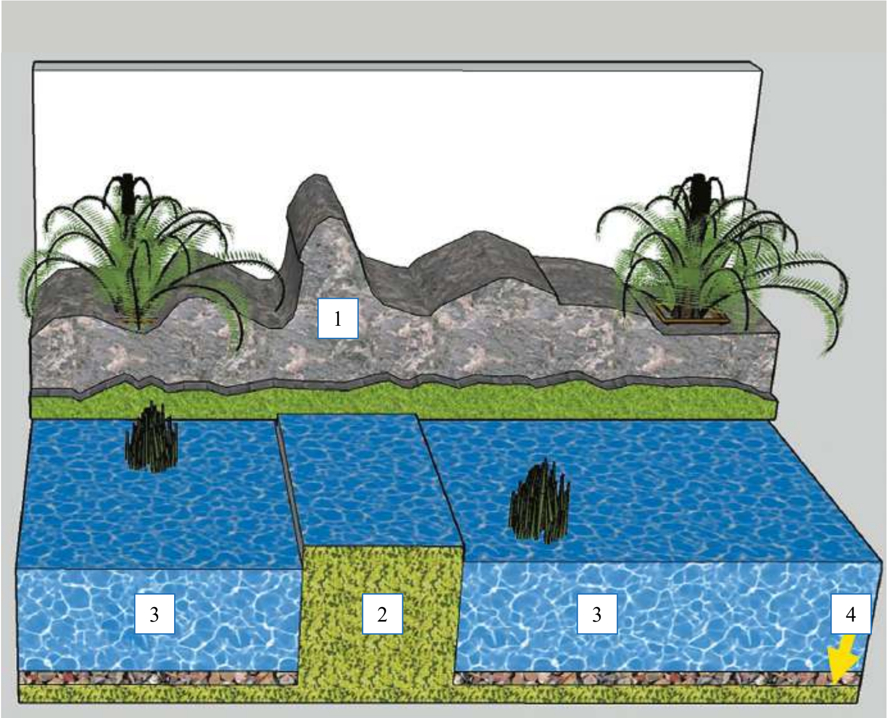

Figure 6 – Visualisation of ecosystem model in an aquarium:
1 – land model; 2 – chlorella and diatom chamber; 3 – water chamber; 4 – cavity under false bottom

The construction is conveniently divided into land part with soil and terrestrial populations and water part with the relevant species and populations.

The water section is divided into open and closed subsections. The closed part is located under the land and includes space for root mass of water-resistant plants. Additionally, there is a mineral load (pebbles) to fix the roots at the bottom

The open part is divided into three sections. In the bottom there is a section with a grid (cavity under false bottom) to ensure fi tration from waste products. The space under the bottom is connected to the second compartment in the structure's lower part for water transfer.

The second water compartment is located in the middle of the aquarium, it is raised by 1.5 cm above the water level and equipped with separating grids from all sides. This section is designed for algae development. On both sides of the second compartment the main reservoirs are placed for living organisms' habitation. Their bottom section is covered with gravel and pebbles.

Model of land surface is required for water resistant plants and small animals. It's divided into three compartments with recesses and holes for plants' roots.

The installation is isolated from the top by a transparent glass. The light source is LED lamp with a wavelength range of 430–740 nm.

Description of Trophic Chains Inside the Enclosed Ecosystem

The enclosed ecosystem prototype is based on processes taking place in natural conditions. In the course of the experiment, the trophic chains existing on the planet were specifi d as the basis for the experiment trophic chains. The following criteria were used to assess the adaptation process: growth and development of organisms, populations number, reproduction dynamics and mortality rate.

Chlorella and diatom algae form the basis for trophic system in the aquatic environment. They consume the basic elements needed for photosynthesis and produce large quantities of organic matter while releasing oxygen. Single-celled organisms are capable of rapid growing of biomass that will be the source of food for aquatic receptors [27]. Single-celled plants are also capable of consuming carbon dioxide and nitrogen substances. In the aquatic environment, animals are the main consumers of organic matters. They release carbon dioxide that is absorbed by the plants [28].

Waste products of aquatic plants, especially dying parts and organs, are gradually decomposed. Parts of aquatic plants are also included in the trophic nutrition chains of aquatic animals. Dying shrimps will be included into the snails' trophic chain. Dead snails will be moped up by the other snails and *Anentome helena,* predatory snail. Figure 7 illustrates all the trophic chains in the developed ecosystem.

A large number of decomposers (microorganisms) together with algae are placed under the false bottom. Herewith, organic matter breaks down into components being an excellent nutrient base for the plants and algae.

Inland trophic interactions are represented by two levels of consumers. Primary consumers are *Aphidoidea spp.*, secondary consumers are *Lasius niger.* These animals coexist in the natural environment. This coexistence system means that ants are in a symbiotic relationship with aphids, while spreading them over the plant and controlling their numbers through eating excessive animals. The ants should also control the plants biomass growth.

Drosera anglica Huds. is planned to decrease the number of aphids and ants. Drosera is an insect-eating plant that is not able to get nutrition elements from the soil. The plant catches insects by its leaf triggered and then consumes its elements over extended period of time. Then this leaf dries up, falls down, and enters into the soil substance cycle.

The inland trophic system is partially connected with the water creatures. The trophic chain includes the following producers: *Medicago sativa L.*, *Polytrichum commune*, *Festuca glauca Lam.*, *Festuca x Lolium,* and *Adiantum capillus-veneris L*. These plants are selected due to their photosynthesis intensity (PI), short stature, and water resistance. Therewith, such plants as *Festulolium* and *Adiantum* act as water purifi rs. They absorb excesses of nitrogen and other nutrients from water. Lucerne acts as a symbiotic organism and binds to nitrogen-gathering bacteria accumulating nitrogen in soil or in tissues of other plants.

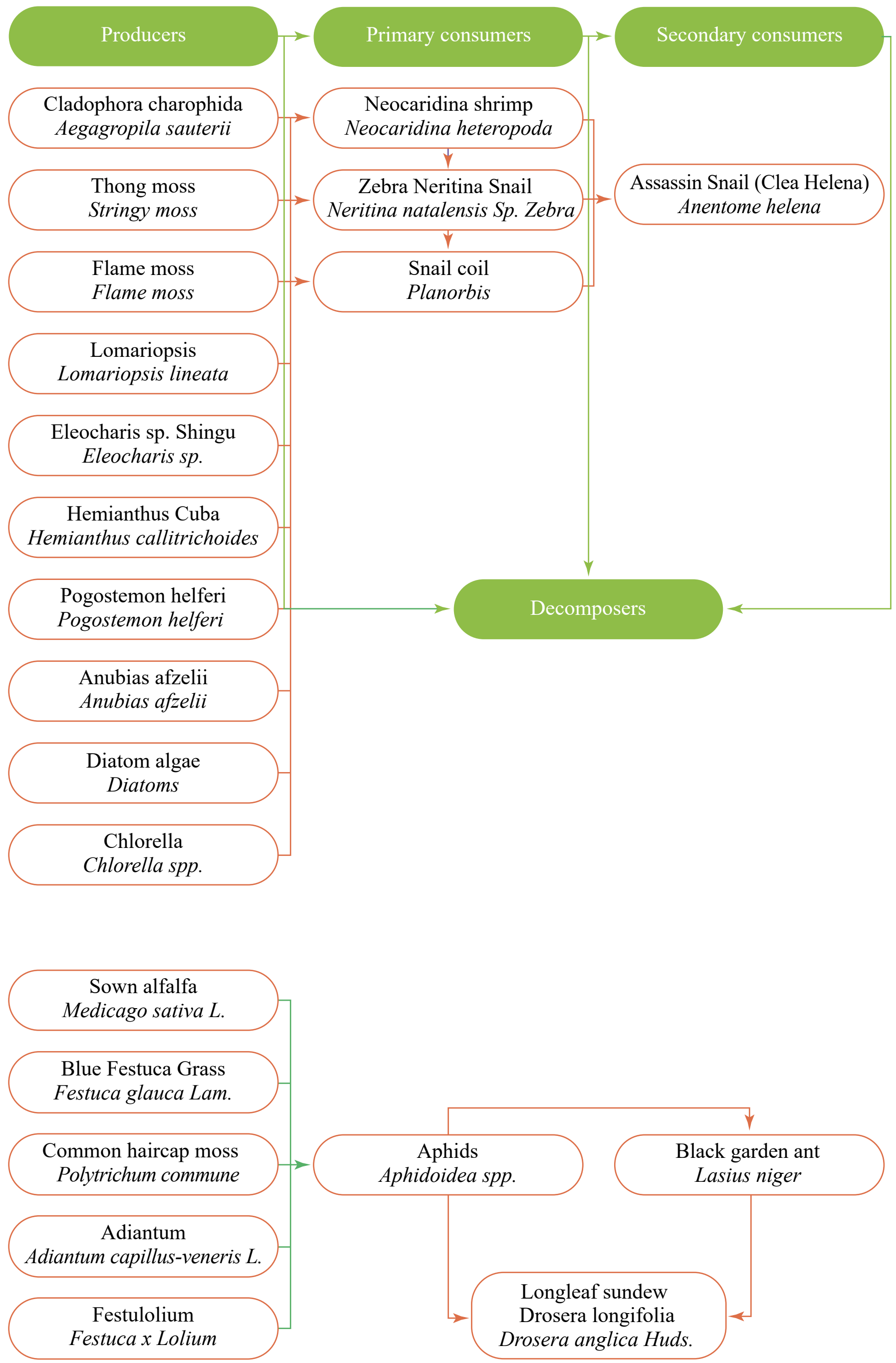

Figure 7 – The developed trophic chains

C. Methodology Description

In order to study the organism adaptation process, it is necessary to specify a number of criteria. There are sustainable growth and development of the population among them.

The experiment is conducted to analyse biomass growth of all producers in the trophic chains. The key parameters are the number of individual plants, the average number of leaves, the average number of stems or branches, and roots growth. Animals growth or mortality rate are also assessed. We analysed such abiotic factors as humidity (%), temperature (°C), and pH. Humidity and temperature were measured with a hygrometer and a thermometer placed in the aquarium. Tetra WaterTest Set quantified pH. The water samples were selected trough an external tube immersed into water sections.

All these indicators allow to evaluate the isolated ecosystem development stages. The population dynamics allows to detect the moment of species adaptation and determine the primary direction of the trophic connections symbiosis development.

D. Results and Discussion

After settlement of the living organisms' populations, the adaptation processes started. This is evidenced by a number of indicators: development and growth of the organisms and population growth.

Table presents indices of plants growth and development. The biomass growth demonstrates the plants' adaptation processes, as well as their intensive mineral and gases consumption from the environment. Leaves growth processes show active light wave absorption and photosynthesis. As a result of these processes, respiration and accumulation of organic matter in plants are activated. Generation of secondary metabolites and large amounts of energy in the form of adenosine triphosphate (ATP) starts. ATP stimulates growth of the plant regenerative organs (stems and roots). This process is actively observed through the example of *Festulolium*. This plant performs a high rate of photosynthesis intensity, as well as high level of sugar accumulation inside its stems.

The experiment results were collected over the 19 days' period (May 6–25, 2020). During this period the ecosystem was in the process of primary adaptation. Observations are still in progress.

Therefore, active development of plants demonstrates stability of the enclosed ecosystem, because plants are very sensitive to light and climate conditions. At the same time, plants are one of the main organisms stabilizing the nutrient chains and gas balance of the whole ecosystem.

The plants suffer from shortage of carbon dioxide in the enclosed ecosystem. Growth of the biomass was observed in the context of transpiration adaptation (balance of the consumed gas). The competition decreases with acclimatization and development of population size. The only competition that takes place between all the populations is competition for carbon dioxide between plants and for oxygen between shrimps.

Table – Plants growth and development indices

List of plants	Quantity	Average leaves number		Biomass increasing	Average number of stems or branches		Biomass increasing	Root growth, cm		Biomass increasing
		At the beginning 06.05.2020	By the time 25.05.2020		At the beginning 06.05.2020	By the time 25.05.2020		At the beginning 06.05.2020	By the time 25.05.2020	
Thong moss *Stringy moss*	1	30	45	15	20	25	5	–	–	–
Flame moss *Flame moss*	2	30	45	15	20	25	5	–	–	–
Lomariopsis *Lomariopsis lineata*	2	60	80	20	15	20	5	–	–	–
Eleocharis sp. Shingu *Eleocharis sp.*	2	18	23	5	1	7	6	2	5	3
Hemianthus Cuba *Hemianthus callitrichoides*	30	40	42	2	50	58	8	–	–	–
Pogostemon helferi *Pogostemon helferi*	1	10	12	2	1	2	1	–	–	–
Anubias afzelii *Anubias afzelii*	2	44	46	2	3	8	5	–	–	–
Sown alfalfa *Medicago sativa L.*	2	21	27	6	1	2	1	–	–	–
Blue Festuca Grass *Festuca glauca Lam.*	15	4	5	2	1	2	1	–	–	–
Common haircap moss *Polytrichum commune*	15	18	20	2	1	2	1	–	–	–
Adiantum *Adiantum capillus-veneris L.*	1	46	55	9	9	11	2	–	–	–
Festulolium *Festuca x Lolium*	1	18	23	6	1	6	5	15	19	4
Longleaf sundew Drosera longifolia *Drosera anglica Huds.*	1	6	9	3	1	2	1	–	–	–

Figure 8 illustrates the initial quantity of animals in the ecosystem. During the observation time the number of *Planorbis* increased from 6 to 23; *Aphidoidea spp.* increased from 30 to 80 individuals; *Neocaridina heteropoda* decreased from 15 to 6 ones.

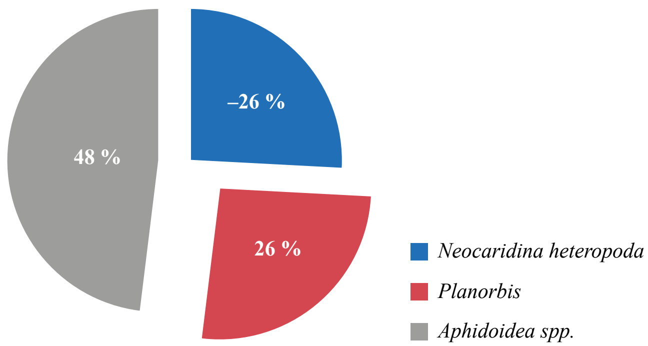

Figure 8 – The initial quantity of animals, %

Due to the long-term adaptation of algae and aquatic plants, a low pH value of the water was recorded at the level of 5.4 on May 26, 2020 because of organic matter depletion. Large amounts of carbon dioxide were released and oxygen level decreased under the influ nce of organic matter oxidation. This pH value caused excess mortality of shrimps, but pH on June 10, 2020 was 7.5, that means good adaptation of plants and algae in the aquatic environment. These processes led to increase in oxygen concentration and neutralization of acidity and, as a result, reducing in the shrimp mortality rate. Next day *Cyclops sp.* was added in the system to regulate the number of neocaridine shrimp. After introduction of the additional consumer, the shrimp population size became stable.

Thus, after reviewing, it is obvious that individual adaptation of organisms passes, however, formation of trophic chains requires more long period of time.

Constant maintaining of stable environmental parameters enables faster population adaptation [31, 35–37]. Isolation of the ecosystem prototype is possible after acclimatization of the main species. According to the observations, it is possible to arrange steady species growth, predator activity, and proper gas balance – oxygen and carbon dioxide intake and consumption by all organisms – in the enclosed ecosystem.

Based on the adaptive processes of populations, we can see that the process is going according to our predictions. Death of some individuals within the population will reduce load on the lower trophic levels, providing its adaptation and biomass growth. However, because of abiotic factors and sharp decrease in some elements' intake, drastic reduction or loss of the main trophic units may occur.

At the first stages of creation of a large enclosed system (that takes larger areas), increased control of the intake and consumption of various inorganic

substances should be carried out. It's also required to monitor the number of species at the moment of their introduction into the enclosed ecosystem. Such monitoring should be stopped when the system becomes balanced. Therewith, we have to study general systems of population dynamics.

In the case of death of a large number of individuals within the population, firstl it's important to study influence of all abiotic factors and then biological factors. Any factor that harms the population have to be removed artificially from the ecosystem. If it's impossible to remove it, trophic chains should be replaced.

E. Conclusions and Perspectives

Creation of the isolated ecosystems requires adaptation of a limited number of living organisms transferred from the global natural ecosystem. All organisms get into a new unbalanced biogeocenosis with new ecological conditions of the enclosed system.

The research results show that it is possible to trace formation of artificial trophic links, observe interaction between living organisms and adaptation processes of the entire population. The rate of plants adaptation to the enclosed conditions was better than the animals did, and it was observed through the active growth of plant biomass. Animals adaptation flowed harder because of their more complicated requirements for environmental conditions. Therewith, trophic links were constructed correctly, and at the time of the experiment there was no any extinct species of living organisms.

There is a number of questions requiring for further study. They are: elaboration of conditions to balance gas exchange in the aquatic environment, additional studies of various trophic systems with laboratory measurements of gas movement. Also, it's important to review intensity of plants' photosynthesis within the enclosed ecosystems. There is a need to develop the enclosed ecosystem model suitable for human living inside of it in order to get the relevant samples. It also worth to note that most plants are sensitive to season climatic conditions.

According to the research it is obvious that the process of living organism's adaptation in the enclosed ecosystem is rather complicated, and within ECH [3] it should be done in stages. These results will be used in future planning and designing of the ECH-Earth, as well as the ECH biosphere nursery in the orbit, where adaptation of living organisms will take over several years. Also adaptation of the elements in the ECH ecosystem may be performed within the mini ecosystems created on Earth, for example, in the capsules of the General Planetary Vehicle (GPV) [3], where the process of adaptation of all living components will start. Then these capsules will be delivered to the orbit ECH, where the balanced soil will be already prepared at the moment. Then these mini ecosystems will be scaled up in the ECH and the plants and animals from Earth will join the local adaptation processes. The further direction of research is focused on development of these solutions.

19.4 Hydrosphere of EcoCosmoHouse on Planet Earth and Its Components

The total volume of Earth's hydrosphere is 1.39 bln km^3 [38]. At present, the state of water objects indicates a significant pollution and gradual degradation of the hydrosphere because of the anthropogenic factors. In most cases, self-purification of natural water is impossible in the face of the mankind technogenic impact [39].

Distribution of water resources throughout Earth and their interrelations make it possible to transfer mineral and organic substances within the biosphere. This process emphasizes the high importance of water bodies for maintaining natural balance. It is worth to mention importance of water in the living organisms. Water provides a binding function uniting all tissues and organs, and a carrying function by managing transfer of useful substances within the body [39].

While creating a model of an artificial ecosystem, the presence of water bodies and their control in an enclosed environment should be considered in detail. Thus, it is necessary to simulate an optimal water circulation while recreating artificially the hydrosphere in EcoCosmoHouse on Planet Earth [3], considering its relevant performance parameters for permanent residence of a group of people in an isolated area. Such simulation should be based on the main hydrological processes occurring on Earth. When implementing this project, it is necessary to analyse a number of aspects: time frame and water circulation in an artificial hydrosphere, types of water bodies, basic and additional purification methods to constantly maintain the required water quality, anthropogenic impact on the state of water bodies, accumulation, and methods of rational use of limited water resources.

Initial design of the isolated ecosystem includes similar allocation of areas for different zones, it means that three quarters are allocated for water resources and one quarter – for land covered zones. With such distribution, it will be impossible to accommodate sufficient number of people and place necessary elements for their living, including houserooms, sufficient areas for farming and animal breeding, areas with trees and plants for oxygen generation. Sizing of these elements should be based on calculations relating to the necessary amount of food for the population.

Another difficulty in the project implementation can be recreation of the natural water circulation with terrestrial cycle duration of eight days [40]. Under restricted conditions, it will be impossible to use natural water vapor as the main source of rainfall without the use of mechanical water lift. Thus, as the process of vaporization and moisture condensation is excluded, fresh water should be pumped into irrigation pipelines equipped with sprinklers and used as a source of artificial rainfall and subsequent redistribution of water within the given area.

Recreation of self-sustainable artificial ecosystem is a challenging process, so the wide pool of details should be considered with the highest priority. The hydrosphere should include fresh and brackish ponds, thermal springs, streams, wetlands, and groundwater. Accordingly, the freshwater pond will act as an accumulator of the surface water, combining a number of functions in itself, such as: cultivation

of plants and valuable organisms, fish farming, irrigation and recreation (bathing, fishing, active and passive forms of recreation in the coastal zone).

A brackish water can act as an isolated seafood farm for growing and cultivating valuable species of organisms and algae, for which this environment is natural.

Waters of a thermal spring with temperature range of 30–35 °C can be used as a natural heat carrier in order to maintain microclimate, as well as for medical purposes. For example, they provide living conditions for a number of sanitizing organisms that are able to clean the human skin.

The water stream acts as a surface filter. Its presence is dictated by the need to arrange surface runoff and ensure constant circulation between the freshwater pond and wetland areas. Wetlands are the most efficient ecosystem on the planet, counteracting to CO_2 accumulation in the atmosphere. Annually, one hectare of such land absorbs between 550–1,800 kg of carbon dioxide from the atmosphere, which is 7–15 times more efficient than a forest of the same area with the subsequent release of 7–15 times more oxygen: 260–700 kg [41]. Swamp moss (sphagnum) is an excellent antiseptic. It does not allow developing of the anaerobic bacteria. In addition, peat in the swamp binds harmful substances into insoluble compounds. These processes enable using water from surface sources for drinking supply, breeding valuable species of fish, regulating microclimate inside the ecosystem and creating a natural self-cleaning filter.

Proper state of the underground water resources can be achieved by ensuring proper infiltration of the ground water through the soils. In this respect, soils act as a sand filter. Smoothly moving from one layer of soil to another, ground water goes through a self-filtration process until it reaches a fresh water reservoir to continue its circulation.

Geotextile is a good solution to create a sand filter as an intermediate filtering layer in order to separate layers of different soils and coarse granular materials. This intermediate layer is needed to prevent wash-out of fertile soil enriched with humus into the lower layers consisting of different chemical and granulometric composition of mineral soils. This, in turn, allows the nutrient solution to be applied to the upper layers of the farming soil for intensive organic processing and to use the lower layers containing different fractions of mineral soil as a sand filter, while avoiding mix-up of adjacent layers. Thus, a purification process can occur, accompanied by enrichment of water with minerals and microelements. At the same time, the total volume of water inside the hydrosphere remains unchanged.

Man has an anthropogenic effect on the hydrosphere in one way or another: by dumping household and sewage into water bodies or by bringing organic fertilisers, herbicides and pesticides in agriculture. Water resulting from human and animal life should be directed to an isolated underground drain so that it does not affect other surface and groundwater bodies without proper purification. It is permissible to mix wastewater with food residues and pre-fine-cut waste of plant origin for subsequent use in humus production (Dano biostabilizer method). Excess moisture can be filtered and accumulated in a settling tank, where the processes of disinfection, purification (activated silt) and enrichment with organic substances (chlorella) take place to be finalized as a nutrient solution (rganic fertiliser).

Subsequently, created nutrient solution may be used for watering and irrigation of crops, trees, and shrubs. Excess moisture generated during irrigation is later filtered into the ground, passing through a natural sand filte . Such filter is made of the following layers: a layer of vegetable soil enriched with humus, underlain by layers composed of sands of various fractions, minerals, and stones. To accelerate the flow of filtered water into a freshwater body, a deep systematic drainage should be arranged under the entire area occupied for cultivation of agricultural crops and other plants. To achieve this effect, perforated polyethylene pipes of various diameters and coarse stone layers can be used.

During implementation of the ECH-Earth project, it should be taken into account that in its construction existing resources will be used with their presented polluted state. Pollution was created by anthropogenic impact in one way or another. The total water reserves on land including waters in lakes, rivers, glaciers, and the underground basin are estimated at 48 mln km^3, which is about 3.5 % of the total volume of all water on the planet. The supply of fresh water is estimated at 35 mln km^3, which is about 2.5 % of the total mass of land waters [40].

Summarising, implementation of the ECH-Earth prototype will allow to analyse in practice and correct (if necessary) the adopted project solutions. Such construction will act as a testing chamber for operation of the entire biosphere and its individual elements. Conducted tests will highlight emergency scenario, help in developing and configuring the maximum number of systems to operate in automatic or semi-automatic mode, as well as excluding all possible emergencies and developing effective measures for their elimination

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20

Special Role of Food as a Building Material for Human Body in Enclosed Biosphere with Limited Dimensions

20.1 Introduction

According to the information from the World Health Organization [1] today humanity faces two problems such as malnutrition and excess weight especially in developing countries. Nutrition is a subsystem which is a key social indicator [2]. Diet violation affects adversely the human body as it increases the risk of development of the socially signifi ant diseases [3]. The global food problem today is the inability of humanity to provide fully itself with food that corresponds to the physiological intake standards [4]. Nowadays, the issue of getting a correct and complete range of vital elements from nutrition is the most significant issue of humanity.

Consequently, the authors think that it is highly important to consider food bioproduction in an enclosed biosphere EcoCosmoHouse (ECH) according to the basic human requirements [5]. Since the biosphere is enclosed, food delivery from the outside is not expected. The object of this work is to define ways of providing ECH's inhabitants with a full range of macro-, micro- and ultra nutrients, vitamins, and other substances which are necessary for a healthy body by using food products produced in ECH.

20.2 Role of Nutrition in Human's Body Functioning

Nutrition is the core process of providing a human with necessary substances to build a healthy body [6–12]. This factor will play a key role in EcoCosmoHouse, i.e., an enclosed biosphere. It is vitally important for a human to replenish the requirement for macro-, micro- and ultra nutrients, vitamins, and other substances included in thousands of complex organic compounds contained in food products (not in so-called vitamin complexes sold by pharmacies) for the normal functioning of all organs and tissues that contain more than 70 chemical elements of the periodic table. Food is not only a source of energy, but also a building material for the human body which health and longevity depend on food quality.

To determine the list of products which are necessary to replenish the requirement for macro-, micro- and ultra nutrients, vitamins in ECH, it is important to know the average daily intake requirements of an average person. Table 1 provides a summarised data, based on the literature review, of the chemical components of the humans' nutrition [9, 13].

Table 1 – Daily average human requirement for micro-, macronutrients, and vitamins

Component	Daily average requirement	
	Men	Women
1	2	3
Calcium	1,000 mg	
Phosphorus	700 mg	
Magnesium	300 mg	350 mg
Sodium	550 mg	
Potassium	2,000 mg	
Iron	10 mg	
Iodine	150 mcg	200 mcg
Fluorine	3.1 mg	3.8 mg
Zinc	7 mg	10 mg
Selenium	30–70 mcg	
Copper	1–1.5 mg	
Manganese	2–5 mg	
Chromium	30–100 mcg	
Molybdenum	50–100 mcg	
Arsenic	50–100 mcg	
Plumbum	10–20 mcg	
Germanium	0.8–1 mg	
Gold	2–4 mcg	
Cadmium	10–35 mcg	

The end of Table 1

1	2	3
Vitamin C	50–100 mg	
Vitamin B_1	1.4–2.4 mg	
Vitamin B_2	1.5–3 mg	
Vitamin B_6	2–2.2 mg	
Vitamin B_3 (PP)	15–25 mg	
Folic acid	0.2–0.5 mg	
Vitamin B_{12}	2–5 mg	
Vitamin A	0.5–2.5 mg	

It should be taken into account that ECH is an enclosed ecosystem, so all organic substances and materials should be environmentally friendly, easy to produce and to process. It is important to achieve not simply the presence of the certain micronutrients in food products, but also a balance of the nutrition elements in general. For example, you need to eat 12.5 kg of cucumbers to get a daily protein intake, but such an approach to a diet compound has no common sense.

If agricultural products have a low concentration of certain micronutrients, for example, zinc, molybdenum, or germanium, they won't affect human body in a positive way. It is extremely important to analyse the range of necessary micronutrients which is contained in agricultural products grown on fertile soil, whether it contains the all range of 70–80 chemical elements in right proportions and compounds which our body is able to absorb. Currently, the biological role has been identified for about 30 basic macro-, micro- and ultra nutrients. The necessity of the other micro- and ultra nutrients is an ongoing research work. This research shows the manufacturing of bioproducts of the same quality as those grown on the most fertile soil on Earth – chernozem, which is achieved by laying of the full range of necessary soil elements while creating ECH biosphere.

It should be noted that chemical elements do not appear in food products out of nowhere – they should be laid initially in the soil, taking into account the lifecycle of ECH and the cycle of substances in it.

The human body regenerates on average every three months – this is the average life span of cells most of which die and get excreted [14]. They are replaced by the new cells with the help of more than 70 chemical elements of the periodic table [6]. The human consists of approximately 30 tln cells the largest share of which – 24 tln – are erythrocytes or red blood cells. Another trillion are platelets or blood cells, which are responsible for coagulation and only 3 tln cells are the rest of the body [6]. The lifetime of blood cells, which make up to 90 % of all cells, is relatively short. Platelets and leucocytes (white blood cells) have the lifetime of 8–12 days, although erythrocytes (red blood cells) live up to 120 days [6]. Hence, blood cells are consumed in an enormous number – more than 2 mln cells die every second, more than 200 bln per day. These cells are recreated with the support of nutrients supplied with food and water.

20.3 Ways of Calculating the Required Number of Products and Area Under Its Cultivation in an Enclosed Ecosystem

The amount of each product was calculated according to the requirement for micro- and macronutrients presented in Table 1.

It was calculated using the formula:

$$\text{\% of daily average requirement} = \frac{\text{Element content in a product, mg}}{\text{Daily average requirement, mg}} \times 100\,\% \quad (1)$$

The results of calculations were summarised in the shared table, after that the bioproduction needs were calculated for each of the included product.

The calculation of the area under cultivation of each type of plant product, goat farm, poultry farm, rabbit farm, fish farm was performed according to the human requirements for each type of product and associated facility output.

During calculation it was considered that animals (goats, rabbits, quails, chickens, fish, etc.) would be fed both with specially grown food and food production waste (uneatable crop residues, seed meal, etc.).

The area was calculated using the formula:

$$\text{Area, m}^2 = \frac{\text{Annual requirement for product, kg}}{\text{Facility output, } \frac{\text{kg}}{\text{m}^2}} \quad (2)$$

The maximum possible yield of plants and mushrooms, milk productivity of goats, the growth rate of animals and other factors were taken into account during the mathematical analysis.

20.4 Vital Chemical Elements and Possible Sources of Getting Them in ECH

The analysis was done using one element at a time.

Milk and dairy products are the main sources of calcium:

- 100 g of 2.5 % cow's milk contains 120 mg [15] of calcium, which is 12 % of daily average requirement;
- 100 g of 5 % fat quark contains 164 mg of calcium (16.4 % of daily average requirement);
- 100 g of Parmesan cheese contains 1,118 mg (118 % of daily average requirement).

By contrast, chicken egg contains 55 mg of calcium (5 % of daily average requirement). The main way of bioproduction of products containing calcium will be

breeding of domestic animals (cows, goats) in ECH. One cow can give 15–20 l of milk with a fat content of 3.2–5.5 % on average per day. Consequently, in ECH approximately eight cows will be needed to provide 100 people with 800 g of milk and dairy products (in terms of pure milk). Goat's milk can be used as an alternative to cow's milk. The chemical composition and properties of goat's milk are similar to cow's milk, but it has a 10–15 % higher content of nutrients. At the same time, it is much easier to breed goats. The calculations show that 25 goats will provide 100 people with 700 g of goat's milk per day. It should be considered that depending on the demand of ECH's inhabitants some products will be used for making milk, butter, quark, cheese, etc. Milk also contains vitamin D which helps a human body to absorb calcium. Quail eggs can be used as the source of calcium. One quail egg contains 9.8 mg of calcium which is 1 % of daily average requirement. The shell of quail eggs, which can be eaten in a crushed form, contains 98.4 % of calcium carbonate. With a mass of 0.8 g, the shell of one quail egg fills 30 % of the daily requirement for calcium.

The main sources of phosphorus in ECH can be:

- cow's or goat's milk (250 ml of cow's milk contain 200 mg of phosphorus, which is 28.5 % of a daily requirement);
- cheese (up to 200 mg in 50 g of cheese – 28.5 % of a daily requirement);
- chicken eggs (an egg – 60 mg of phosphorus; 8.6 % of a daily requirement);
- quail eggs (an egg – 213 mg of phosphorus; 29.8 % of a daily requirement);
- fish and seafood (up to 300 mg in 100 g depending on species; 42 % of a daily requirement) [16].

Consequently, it is planned to use quail eggs as phosphorus source in the quantity of 3–4 eggs for a person per day. To produce such a quantity of eggs a poultry farm with 450 quails will be needed.

Food sources of magnesium include dark-green leaf crops and vegetables:

- broccoli (140 mg in 100 g of cooked broccoli which is almost 50 % of a daily requirement);
- peas (21 mg in 100 g, 7 % of a daily requirement);
- spinach (314 mg in 100 g, almost 100 % of a daily requirement).

These crops can be grown in ECH. For example, for 100 people with a consumption of 50 g of spinach per day you need to grow 5 kg per day and 1,825 kg per year. The yield of spinach is up to 2 kg from 1 m^2, the growing period is 30 days. It means that only 76 m^2 of an area will be needed.

To replenish a daily dose of sodium, 30 g of Parmesan cheese will be enough. Chicken egg contains 134 mg of sodium, chicken meat – 40–90 mg of sodium. Quail egg contains 21.2 mg of sodium. It is important to note that ECH's inhabitant can replenish the requirement in many micronutrients at once by eating chicken or quail eggs.

The main sources of potassium suitable for ECH's inhabitants will be:

- fruits – bananas (100 g contain 348 mg of potassium), apricots (100 g – 305 mg of potassium), peaches (100 g – 363 mg of potassium);

- vegetables – radishes (100 g – 255 mg of potassium), potatoes (100 g – 568 mg of potassium).

For example, 100 people will require 40 kg of these vegetables per day in terms of potato. The yield of one potato plant is 6 kg per season. Consequently, it will be necessary to harvest seven potato plants to replenish the requirements of ECH's inhabitants per day. In addition, alcohol can be got from potato by fermentation and subsequent distillation which can be used as antiseptics as well as for other purposes.

About 400 g of these products in total will be needed to replenish the requirement for magnesium, potassium, and other micronutrients which are found in large quantities in vegetables, herbs, and mushrooms. At the maximum yield and the use of five-tier planting scheme potato plants will require 160 m^2, other vegetables, herbs, and mushrooms – 220 m^2.

Food sources of iron will be all types of meat products, beans, mushrooms. For example, 100 g of beef liver can replenish up to 49 % of the daily average dose of iron, 100 g of shelled peas – up to 50 %. To replenish up to 100 % of the daily average iron requirement, 200 g of rabbit meat can be used. A 900-head rabbit farm will be required to provide ECH's inhabitants with 200 g of rabbit meat per day.

The daily average requirement of ECH's inhabitants for iodine will be replenished by eating sea fish (100 g contain up to 100 % of a daily requirement). It is planned to integrate 50 g of sea fish and seafood in ECH's inhabitants' nutrition to replenish the requirement for iodine. This will require a fish farm with an area of 450 m^2.

Among the availability of ECH's inhabitants sources of fl oride, walnuts (100 g replenishes 32 %) or mackerel fish (100 g replenishes 35 %) can be noted. To replenish the missing amount of fluoride and other important micronutrients for ECH's inhabitants, 20 g of walnuts per day will help. Low-growing, perishable varieties of walnuts in ECH will require 110 m^2 with a five-tier planting scheme for growing.

Products as chicken or quail eggs, cheese, beef, rabbit, buckwheat (in terms of 100 g) will replenish about 20–30 % of the daily requirement of zinc. It is proposed to eat 170 g of cereals to replenish the requirement of zinc and other micronutrients. It will require 200 m^2 for cultivation using a five-tier ystem.

Quail eggs will also be the main source of selenium (100 g of quail eggs replenish 98 % of the daily requirement). There can also be used 5 % quark (100 g replenish up to 55 % of the daily requirement of selenium).

The sources of copper and manganese can be chickpea, lentil, buckwheat (up to 70 % of the daily requirement for 100 g of the product).

ECH's inhabitants can get chromium from beets (100 g contains up to 40 % of the daily average dose), mackerel fish (100 g to 45 %).

The source of molybdenum can be green peas, lentil, bean (100 g contains up to 100 % of the daily average requirement).

Edible shellfish, some types of marine fish can be considered as the richest source of arsenic in food (100 g contains up to 100 % of the daily requirement). The nutrition of modern human contains a sufficien amount of arsenic and does not require

its additional intake. On the contrary, agricultural manufacturers are constantly seeking to reduce arsenic content in food products due to its toxicity.

Just recently, scientists believed that germanium is completely useless for humans and does not perform any function in the body of living organisms. However, studies [13, 17] have shown that individual organic compounds of this chemical element can be successfully used even as medicinal compounds, although it is too early to speak about their effectiveness. Experiments performed on laboratory rodents show that even a small amount of germanium can increase the life span of animals by 25–30 %, and this is a good reason itself to think about its benefits for humans

Germanium is found in garlic – up to 100 % of the daily requirement per 100 g (the most content of it), wheat bran, beans, porcini mushrooms, tomatoes, fish and seafood (in particular, squids, shrimps, and mussels), seaweed, and milk.

The highest gold content is in corn (100 g contains up to 25 % of the daily requirement), in its grains, leaves, and stems, as well as in honey products, in meat, ocean fish cavia , in *Erysimum grey* (herbaceous plant).

If there is an insufficien intake of cadmium to a body (less than 0.5 mcg per day), a deficit of this element can be developed in the human. The main form of cadmium deficiency is growth of impairments. It was observed in laboratory animals with artificial cadmium deficienc . Cadmium is found in oysters, mussels, cabbage, spinach and sorrel, basil, parsley and dill, cereals.

The daily average dose of vitamin C can be replenished by consuming 100 g of cauliflowe , broccoli, 50 g of porcini mushrooms, 90 g of black currant, 90 g of bell pepper.

About 60 % of the daily average dose of vitamin B_1 is contained in 100 g of green peas, 123 % from the daily requirements is held in 100 g of sunflower seeds. Five quail eggs replenish 28.6 % of the daily average dose of vitamin B_1. Just 100 g of chicken protein replenishes 33 % of the daily average norm of vitamin B_2, 100 g of beef liver have 122 %.

About 20–40 % of the daily average norm of vitamin B_6 can be found in 100 g of buckwheat, rice, millet, wheat cereals, chicken meat, walnuts.

From 60 % to 70 % of the daily average dose of vitamin B_3 (PP) can be received by consuming 100 g of chicken meat, turkey meat, rabbit meat, beef liver.

To replenish 20–30 % of the daily average dose of folic acid (vitamin B_9), 100 g of spinach, avocado, lentils, porcini mushrooms, cress, bean should be consumed.

Vitamin B_{12} is found mainly in animal products. The daily average requirement can be replenished by eating beef liver, beef, eggs, and cheese.

The daily average requirement of vitamin A can be replenished by eating 100 g of celery, chicken yolk, spinach, parsley, dill, two quail eggs.

Honey in an amount of at least 10 g for a person per day is proposed to eat as an immunomodulator, a source of a large range of micronutrients and fast-digesting carbohydrates.

Table 2 shows the main products as well as the requirements for their bioproduction in ECH taking into account the year-round cycle. The list of products was selected based on the above calculations of the composition of the necessary components.

Table 2 – Products and requirements for their bioproduction in ECH for 100 people

Product	Consumption per day, g		Requirements for bioproduction
	Men	Women	
Potato	420	380	160 m^2 (planting in five tiers. Total height is about 6 m)
Cereals	180	160	200 m^2 (planting in five tiers. Total height is about 6 m)
Vegetables, herbs, and mushrooms	430	370	220 m^2 (planting in five tiers. Total height is about 6 m)
Fruits, berries, medicinal herbs	210	190	100 m^2 (planting in five tiers. Total height is about 6 m)
Quail egg	56 (four eggs)	42 (three eggs)	A poultry farm. The quantity of quails is 450, the area is 50 m^2 (it is placed in five floors the poultry farm is on the first one, where cages are placed in 3–4 tiers, the cultivation of grain is on the other floors. The total height is about 7.5 m)
Dairy products from goat's milk	750	650	A goat farm for 25 heads. The area is 100 m^2 (it is placed in five floors: the goat farm is on the first on the cultivation of feed is on the other floors. The total height is about 7.5 m)
Rabbit meat	210	190	A rabbit farm for 900 heads. The area is 90 m^2 (it is placed in five floors: the rabbit farm is on the first o the cultivation of feed is on the other floors. The total height is about 7.5 m)
Fish, crustaceans, shellfis	55	45	A fish farm with the area of 450 ^{2} (it is placed in five floors the fish farm is on the first one, the cultivatio of feed for other animals is on the other floors The total height is about 6 m)
Nuts	20		110 m^2 (planting in five tiers. Total height is about 7.5 m)
Honey	10		5 m^2 (it is placed with flowering plants

It should be considered that these results are preliminary, as they are based on the common terrestrial agricultural technologies with the highest efficien for the given conditions. During the organisation of bioproduction within ECH environment, fundamentally different solutions can also be used, both according to the methods of getting plant and animal products (e.i., the use of aero- and hydroponics but not on mineral substances, but on liquid biohumus, the use of alternatives to goat's milk, etc.) and according to the used sources of nutrients for human (e.i., the use of insects and small animals, including soil, chlorella, and other unicellular green algae, unicellular yeast fungi, etc.). For example, the earthworm has been used in Chinese folk medicine for more than 5,000 years as a source of microorganisms necessary for our digestion (the human gut, which is the basis of its immune system, contains tens of trillions of microorganisms

of thousands of species, mainly soil) and many medicinal substances containing essential micro- and ultra nutrients.

The paper describes an approach that in theory allows to get a completely healthy nutrition without any extreme options, such as eating only easily cultivated vegetables and green algae. Optimisation of bioproduction is necessary, especially in conditions of limited resources and space, but it does not mean that the quality of food should be reduced.

20.5 Conclusions and Further Research Directions

Based on the above, it can be concluded that the nutrition of an ECH's inhabitant should include a range of products containing all macro-, micro- and ultra nutrients, vitamins, and other vital substances. There is a list of products which production should be established in ECH environment. Thus, if there is a serious optimisation of getting bioproducts in regard to earth conditions, it will be possible to provide 100 people living in ECH with food, using only about 1,500 m^2 of area for bioproduction.

It is planned to extend the research, make a common list of optimal food products and methods of their bioproduction and also consider in details the possibility of organic waste utilisation to return it to the manufacturing cycle.

In the future it is planned to develop various types of nutrition elements (halal food, kosher food, vegan food), explore the ways to optimise food production for humans, detail species diversity of living organisms used in ultra production, calculate production cycles in details, taking into account waste processing, and thus unite the animal and plant world of ECH into a complete ecosystem.

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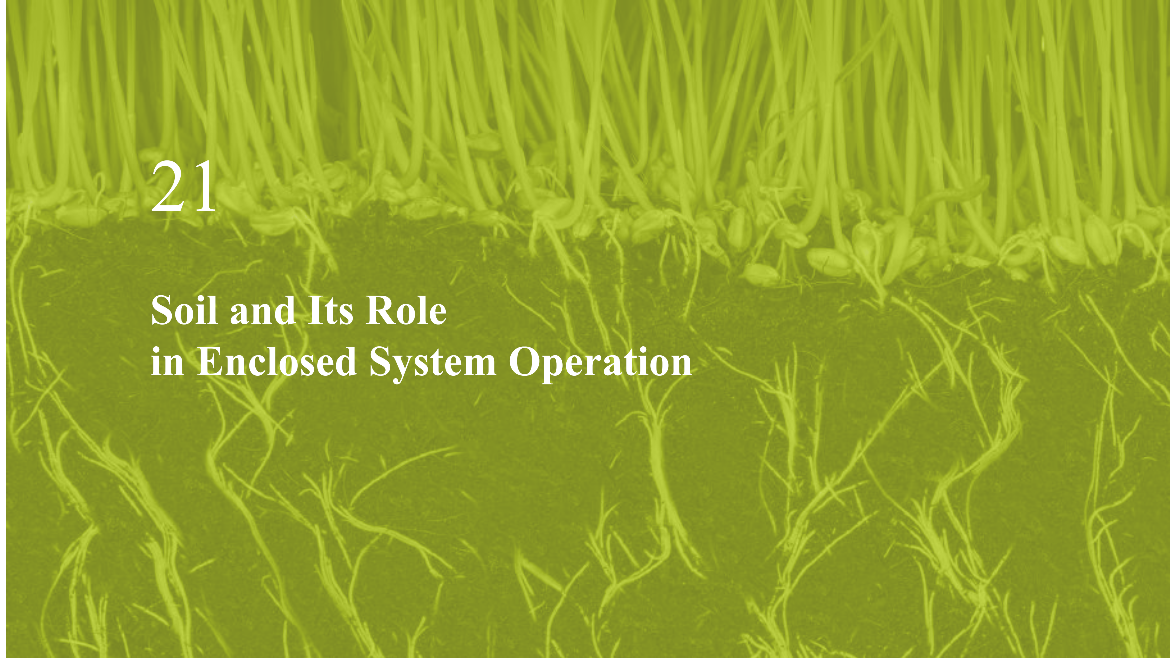

21

Soil and Its Role in Enclosed System Operation

21.1 Role of Soil in Circulation of Macro- and Micronutrients Between Living Organisms in Isolated Enclosed Ecosystems

For years, various chemical substances including fertilisers and pesticides (herbicides, insecticides, fungicides, etc.) have been applied to the agricultural soils which were also affected by mechanical actions [1]. Such intensive agriculture results in deterioration of soil compound and its erosion followed by depauperation of aerobic and anaerobic bacteria, animal species extinction (for example, earthworms), and, fin lly, accumulation of certain toxic substances [2, 3]. In some cases, there is a micronutrients oversupply. For instance, the ideal soil composition contains up to 3,8 % of iron [4]. Increase in iron concentration leads to soil acidification and low pH level, therefore plants stop growing and developing.

According to the studies by the Food and Agriculture Organization of the United Nations (FAO) [5] and V. Vernadsky's theory [6], as a part of the biosystem soil is the main source of nutrients for plants while providing pathogen load decrease. Soil contains a significant amount of various minerals existing in any life form (macronutrients, micronutrients, and nanonutrients). In addition, soil includes a number of organic substances for microorganisms' nutrition.

Both organic and inorganic chemical compounds contained in soil are absorbed by plants and bind with their organic matters in parenchyma. Due to this process plants accumulate active compounds and energy that are transferred then to animals and humans via the trophic chains either bound or free [7]. Generally, these chemical elements serve to synthesize new more complicated components for human or animal tissues and organs. The study of the nutrients circulation process allows definin an optimal soil composition for the enclosed ecosystem of EcoCosmoHouse (ECH), which is a type of space colony on the Earth's orbit [8].

The present research is intended for developing methods to consider transmission of selenium, iodine, and copper from soil to animals via plants. It is based on the theoretical analysis of the soil mineral composition that is optimal for plant food production, as well as the study of plant influence on the trophic chains as an intermediate stage of vital nutrients transmission from soil to humans and animals.

A. Circulation of Substances Between Trophic Levels

The main soil fertility properties depend on its chemical compound including contained mineral components [4]. Plants are nourished by nutrients from soil. There are two ways of plant nutrition, they are autotrophic and heterotrophic. Heterotrophic nutrition takes place only during seed germination. The germ consumes biopolymers from the endosperm with the help of enzymes [9].

Autotrophic nutrition comes around during all stages of plant life and is implemented by the photosynthesis process. Alongside photosynthesis, green plants also need to get marco- and micronutrients from soil through their roots [10].

Plants consume a large amount of soil mineral elements during formation of their primary and secondary tissues. In the course of their life, consumption of the mineral elements significantly decreases. Furthermore, the mineral nutrition intensity directly depends on life forms adaptation to external conditions [9].

The most optimal mineral compositions for the growth of plant cells and tissues are defined. The *in vitro* method based on Murashige and Skoog nutrient medium, which is essential for the range of crops, is widely adopted for cell nutrition and isolated tissue cultivation [11]. This solution was developed subject to the specifi s of root nutrition, whereas it is the most common way of nutrients supply from the soil-forming solids. Dissolved mineral salts are fed to the rhizosphere and transferred toward the root centre, where xylem and vascular bundles are located. Through the xylem, water with mineral salts is transferred to the leaf plates or other vegetative or reproductive organs [12].

Hereafter mineral salts diverge in leaf intercellular spaces and penetrate to the cells through a semi-permeable membrane. There are various physiological processes which occur in the plant cell under the influence of enzymes and proteins [12]. Incoming salts are destructed inside the cell and integrated into organic compounds. Macro- and micronutrients are stored in the cell plastids (leucoplasts) or engaged in the cell biochemical processes. So, consumption of macro- and micronutrients is performed gradually and at a steady pace [11]. Some of macronutrients in plant compounds may be toxic to human, for example, nitrites (NO_2^-) and nitrates (NO_3^-). These chemicals are harmless for plants and often serve as nitrogenous nutrition. Plants mostly get these elements from mineral fertilisers and organic substances [12].

At the moment there are a lot of known soils with optimal composition for plants cultivation [13] and black humus soil is among them. It contains a huge amount of chelate macro- and micronutrients and microorganisms [14]. Chelates are easier taken up by plants [15].

Life activity of soil organisms (worms, insects, bacteria, and fungi) results in accumulation of organic matter known as humus. Humins and humates are the main elements of humus. These substances have a direct impact on plant growth. Moreover, humus contains a variety of biopolymers formed after the organisms' life activities and from the remains of plants or animals. Soil decomposers destroy these biopolymers and thereby provide a nutrient constituent for plants [16] which are highly organised life forms having close symbiotical tides with fungi and even bacteria [17].

Therefore, the soil composition has a direct impact on plant growth and development. In their turn, plants influence organisms for which they serve as a nutrient. It is possible to observe transfer of all chemical substances from soil to human. The present section describes transfer of selenium, iodine, and copper. These nutrients were selected because their deficiency may result in serio s diseases with reference to both humans and animals [18–20]. Furthermore, these nutrients are important for plant growth and development [21–24]. Meanwhile, transfer of selenium, iodine, and copper through plants has not been studied before.

Selenium is needed for normal functioning of endocrine, immune, reproductive, cardiovascular, and nervous systems of human body [18]. More than 40 human diseases are caused by deficiency of this nutrient. Selenium plays an important role in thyroid gland functioning: it is an essential part of the enzyme (iodothyronine deiodinase) providing conversion of thyroxine into the active form that is triiodothyronine; as well as selenium is also functionally related to vitamin E. Therewith, it forms an inherent part of the enzymes neutralizing reactive oxygen intermediates, i.e., glutathione peroxidase. Daily requirement of selenium is 75 mcg for men and 60 mcg for women [18].

For plants, selenium is found in antioxidant enzymes (catalase, peroxidase). The main function of the antioxidant system is inhibition of oxidation processes. That protects the body from excessive influence of free radicals, which are actively generated during the stress reaction [21]. Additionally, selenium has an impact on the overall protease activity, including the whole plant biochemical state. Moreover, this nutrient is actively involved in seed growth and development processes [22].

Iodine is a component of the thyroid hormones (thyroxine and triiodothyronine); therefore, it is selectively accumulated by the thyroid gland. These hormones regulate metabolic rate and coordinate functioning of all organs and systems [19]. Iodine daily requirement is 150 mcg for adults, while maximum permissible dosage is up to 300 mcg. During pregnancy and lactation, the recommended amount is 175–200 mcg [19].

Iodine is not the most important nutrient for higher plants, but it stimulates root growth, improves carbohydrate metabolism, raises ascorbic acid synthesis, and supports formation of free amino acids in water plants [23].

Similar to selenium, copper is an essential part of active and allosteric sites of numerous enzymes, including cytochrome oxidase. Cytochrome oxidase is the last enzyme of the mitochondrial respiratory chain. The molecule consists of two hems (iron atoms inside), two copper atoms, and 20–30 % of lipid component. The main function is turning O_2 into H_2O. Moreover, copper is used to integrating iron into haemoglobin responsible for gaseous exchange in organs and tissues. It is also involved in conversion of tyrosine amino acid into its relevant state responsible for hair and skin pigmentation. Copper is absorbed by the intestines and then it is transported to the liver. Therewith, this nutrient also participates in formation of collagen, elastin, and endorphins synthesis [20]. The recommended daily requirement of copper is 700 mcg for an adult [20].

Copper is a part of plant redox enzymes. It's also a component of enzymes involved in photosynthesis and acts as a process accelerant, as well as provides chlorophyll formation. When copper supply is sufficient plant resistance to bacteriosis and fungous diseases is significantly increased [24]

In the course of work on the current issue, certain data on separate transfer or accumulation of soil substances in plants [7] and energy transfer within the trophic chain was detected [11, 12]. However, there are no experiments regarding these elements gain in animals' health and evaluation of their active compounds in soil composition where food is being grown.

B. Description of the Experiment and Research Methods

Usage of soil as the main source of nutrients for plants is a basis of human and animal health within ECH [8]. Thereby, it is needed to use the soil which will provide the orbit residents with all the necessary nutrients.

Table 1 includes optimal organo-mineral soil composition to meet the plants' needs [1]. Additionally, it is necessary to supply nitrogen elements and other organic substances. Nitrogen, phosphorus, and potassium will enable primary synthesis of organic substances. This process will increase plants' biomass and provide accumulation of useful minerals such as selenium, iodine, and copper.

Table 1 – The optimum organo-mineral soil composition for plant cultivation [1].

Indicator	Value
Labile phosphorus P_2O_5, mln^{-1}	250–150
Exchange potassium K_2O, mln^{-1}	250–170
Nitrate nitrogen NO_3^-, mln^{-1}	20
Ammonium nitrogen NH_3^+, NH_4^+, mln^{-1}	40
Humus content (C org*1.724), % of soil mass	6–10
pH	6.5–7
Selenium, mg/kg of soil [20]	160
Iodine, mg/kg of soil [20]	5
Copper, mg/kg of soil [20]	10

The research will be performed on laboratory animals (rats).

Research object is combination of the fertile soil and microgreens, which include: sowing pea (*Pisum sativum L.*), kidney bean (*Phaseolus vulgaris L.*), common flax (*Linum usitatissimum L.*), milk thistle *(Silybum marianum L.*), common wheat (*Triticum aestivum L.*), common rye (*Secale cereale L.*), common oat (*Avena sativa L.*), common buckwheat (*Fagopyrum esculentum Moench*), lentil (*Lens culinaris Medikus*), common sunflower (*Helianthus annuus L.*), common beet (*Beta vulgaris L.*), common squash (*Cucurbita maxima Duchesne*).

Analysis of macro- and micronutrients content in soil will be carried out according to Peive and Rinkins's methodology [25–27].

The plants shall grow up to three leaves and prior to their analysis for the investigated substances content. Harvested and analysed microgreens, which will not be used at the moment, shall be shock-frozen at a temperature of –50 °C and then stored at a temperature not over –10 °C.

After achievement of the analysis results, the plant biomass can be used for feeding the experimental animals.

The next stage in the analysis process is intended to estimate the amount of the animals' active substances which contain selenium (glutathione peroxidase), iodine (thyroxine, thyroid hormone), and copper (cytochrome oxidase).

Laboratory rats' glutathione peroxidase activity will be determined in hemolysates according to Moine's method [28]. Selenium content in test samples will be determined fluometricly with the use of special selenium-sensitive compound that is 2.3-diaminonaphthaline [29].

Thyroxine and triiodothyronine content will be determined through the enzyme-linked immunosorbent assay (ELISA) [30].

Cytochrome oxidase content in the laboratory animals' skeletal muscles will be determined by the NADI reagent (its main active substances are α-naphthol and dimethylparaphenylenediamine) [31].

C. Conclusions and Further Research

In accordance with the research and theoretical background, optimal composition of soil towards its organo-mineral components has been defined. Then the certain mixed soils will be composed and complementarily investigated on the ground of the obtained data.

Resulting from the theoretical studies, it is possible to analyse copper, selenium, and iodine and their ability to be transferred from one trophic level to another. The reviewed materials enable us to perform the experiment in order to test out data on the soil's qualitative influence on mineral elements transfer to plants and then to animals.

Going forward, it is planned to conduct the experiment on laboratory animals (rats) and test the theoretical background. The research results will display content of selenium, iodine, and copper in the soil samples, as well as their quantitative volume, transferred to plants and then to animals. It is assumed that animals consume the nutrient by its inclusion into the enzyme and hormone molecules. Due to the data which will be obtained in the course of the research, it will be possible to evaluate transfer of nutrients from soil to living organisms through plants, capability to regulate thyroid endocrine profile, as well as functioning of antioxidant fermentative system.

21.2 Soil and Soil-Based Microorganisms in EcoCosmoHouse Biosphere

Soil is a key component of Earth's biosphere, and in combination with soil microorganisms, it performs a medium for a number of important processes, and the circulation of biogenic elements is among them.

Soil is one of the most favourable and permanent habitats of microorganisms. Their number in 1 g of soil is estimated in millions and billions of cells. Soil can be considered as a bank in which various types of microorganisms are stored, or as the gene pool of the microworld [32]. The world of soil microorganisms is very diverse. It includes bacteria, actinomycetes, fungi, algae, and protozoa performing important ecological functions through the successive replacement of one microbial community with another.

The famous Belarusian scientist O. Koleshko has quite comprehensively characterised importance of soil microorganisms for the ecosystem [33]. Microorganisms participate in mineralization of plants and animals' residues, carry out circulation of substances and energy, replenish the nitrogen reserve of soil through biological nitrogen fixation, solubilize phosphorus from organic and poorly soluble inorganic compounds, as well as enrich soil with biologically active compounds (enzymes, amino acids, auxins, vitamins, etc.) and antibiotic substances that inhibit the development of phytopathogens. Mushrooms, actinomycetes, capsular bacteria, and earthworms are involved in the formation of a solid lumpy structure that improves the soil air-and-water regime. Thus, the soil microorganisms play an important role in the processes of soil formation, maintenance of fertility, optimisation of plant nutrition, as well as other geochemical processes.

Nowadays, anthropogenic impact on soil is a serious challenge. The excessive use of chemical fertilisers and pesticides violates soil fertility by changing the composition of soil microflora and its activity. This leads to degradation of the arable lands. The use of agrobiotechnologies in agricultural practice, including active strains of microorganisms that have a range of useful properties, is an alternative way to increase soil fertility, improve crop yields, and obtain environmentally safe products.

In this regard, the purpose of our research was to specify an optimal structure of the soil microbial cenosis under EcoCosmoHouse [8] conditions. ECH includes all the necessary diversity and number of microorganisms, similar to the fertile soil composition of, consisting of natural humus and various types of soil microorganisms participating at all levels of substances circulation.

Agronomically valuable soil microorganisms were singled out from the soil samples non-involved in agro-industrial production. The samples were taken from various regions of Belarus, Russia, and Ukraine. Furthermore, the study included biohumus aged for six months, sandy soil from the United Arab Emirates, and samples of brown coal from the Brinevskoye mine (Belarus). The analysis was performed in the agrotechnical research laboratory at Unitsky String Technologies Inc. The soil sampling was carried out by the envelope method (the average sample of five points) into sterile plastic bags. The main ecological-trophic groups' identification was performed by swab test in agarized mediums: amylolytic bacteria and actinomycetes – in a starch-ammonia medium, oligotrophic – in Ashby medium, cellulose-decomposing – in Imshenetsky medium, ammonifying bacteria – in meat-and-peptone agar, phosphate-solubilizing bacteria – in Muromtsev medium [34]. The selection of brown coal decomposers was carried out in a medium where crushed brown coal was a sole source of carbon and nitrogen with a concentration of 0.01 % of dry matter [35]. The brown coal processing by microorganisms was evaluated by the medium colour intensity upon the glucose addition and in the absence of carbohydrates, as well as changing a number of the colony forming units (CFU). The vitality of the selected microorganisms associations introduced into the soil samples on the basis of crushed brown coal was considered by swab test in agar nutrient media in three months.

The phytotoxicity of the selected microorganisms associations was tested with the use of the watercress seeds because this culture is the most sensitive to inoculation.

The eff ctiveness of the selected soil microorganisms was established under the photo-room conditions in the course of green crops inoculation (Lollo Ross lettuce and arugula) based on the Unitsky's Farm Enterprise technological foundation (Belarus).

The total number of microorganisms in the samples of brown coal was about 10^7 CFU per 1 g. Two associations of microorganisms were defined subject to their destructive activity in relation to brown coal. Also, the mentioned microorganisms are able to transform humic substances. While studying the behaviour of the microorganisms using humic substances of brown coal (in the course of one month), we have observed a microbial decomposition of the coal, as well as the medium turbidity and decrease in its colour intensity. The discoloration was stronger in the flasks containing an additional 0.01 % of glucose (Figure 1).

The collected data indicates that decomposition of humic substances is performed more intensively in the presence of glucose, i.e., under the conditions of cometabolism.

The number of microorganisms-decomposers of brown coal increased on average by an order (10^9 CFU/ml) on the 10^{th} day of the cultivation in the medium containing crushed brown coal as the sole source of carbon and nitrogen; it is obvious that development of the selected bacteria in the mentioned medium is possible.

Eighteen associations of aerobic and anaerobic microorganisms of various agronomically valuable groups: ammonifying, oligonitrophilic, including nitrogen-fixing cellulolytic (mesophiles and thermophiles), phosphate-solubilizing, as well as those using mineral forms of nitrogen were singled out from soil samples not involved in agro-industrial production, as well as from sand, and biohumus sample.

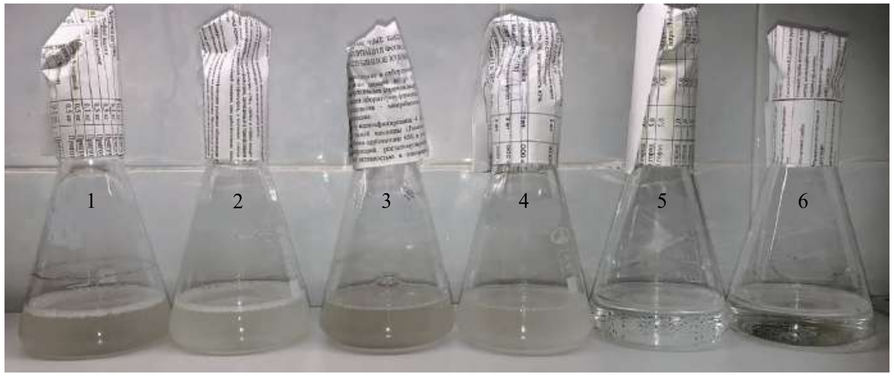

Figure 1 – Ability of selected associations of brown coal decomposers to process humic substances:
1 – association No. 1, cultivated on the medium with brown coal (0.01 %);
2 – association No. 1 (0.01 % of brown coal and 0.01 % of glucose);
3 – association No. 2 (0.01 % of brown coal);
4 – association No. 2 (0.01 % of brown coal and 0.01 % of glucose);
5 – control 1 (medium with 0.01 % of brown coal);
6 – control 2 (medium with 0.01 % of brown coal and 0.01 % of glucose)

Testing of the identifi d microorganisms associations for phytotoxicity showed that the watercress inoculation with bacterial cultures accelerates the seeds' germination. The increase in phytomass of the plants with inoculated seed was 26–71 % compared with the untreated ones. The maximum increase in phytomass was observed during the seed inoculation by the oligonitrophilic bacteria due to their nitrogen-fixing ability, as far as nitrogen is an extremely important element at the initial stage of plant growth and development. An additional positive property of the nitrogen-fixing bacteria is performing the phytohormones synthesis (auxins, etc.).

Based on the separated microbial associations, a bank of microorganisms has been built up. It covers more than a thousand species considered as being of interest for various microbiological and biotechnological purposes (Figure 2).

Figure 2 – Bank of agronomically valuable groups of microorganisms

To get the soil composition similar to fertile one, the associations of soil microorganisms containing all the necessary bacterial diversity and quantity which were taken from different soil-climatic zones were used. Brown coal crushed by the electro-hydraulic method (Bolshesyrskoe mine, Krasnoyarsk Region, Russia) with addition of ash as a source of microelements was used as a carrier and nutrient medium for the microorganisms. Ash was derived from burning of the same brown coal. Electro-hydraulic effect destroys the molecules of humic substances, and microorganisms consume them easier. The technological scheme of soil production is presented in Figure 3.

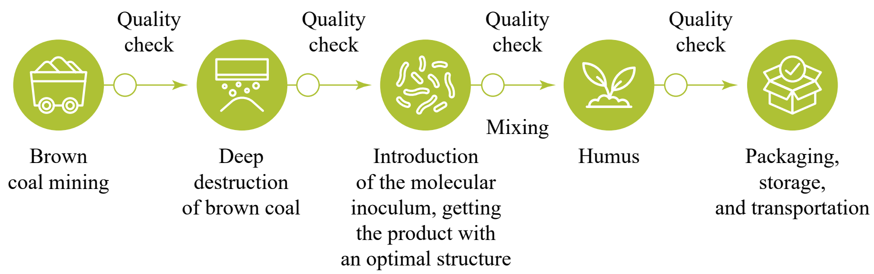

Figure 3 – Technology of soil (humus) production

The microorganisms' association survival rate on the developed soil was studied for three months. The number of introduced microbial species changed insignificantly during the soil storage. By the end of the storage period, the concentration of the microorganisms in the soil was not less than 2.5×10^9 CFU/g. This indicates that the introduced microbial cultures are able to exist there for a long time.

In the course of observation over the developed soil effectiveness under the model conditions in light-house, the phytomass of the studied lettuce crops increased by more than 150–200 % compared with the plants in a substrate based on sand and peat mixed in the proportion 2 : 1. In order to confirm the observed effectivene s during the plants' cultivation plants upon the laboratory conditions in the developed soil, a field experiment on triticale has been started

Thereby, the selected associations of microorganisms and the soil developed with their involvement intensify the plants' growth and development by providing them with all the necessary nutrients and natural growth regulators.

21.3 Potential of Using Cellulolytic Microorganisms to Biodegrade Municipal Solid Waste

Annually, millions of tons of waste are generated on planet. Its accumulation leads to environmental pollution negative impact on the state of human health.

A significant part of municipal solid waste (MSW) is made up of hard-to-degrade cellulose wastes (paper) and plastic products**.** Then the food (organic) wastes are considered [36]. Today, the most common methods of MSW disposal are landfills, incineration, and separate collection of waste with its subsequent processing and reuse [37]. In the process of MSW storing at landfills, the toxic substances contained in MSW or evolved during its uncontrolled degradation under the natural conditions enter the soil and groundwater and cause harm to all life forms. Waste incineration also has a negative impact on the environment [37, 38]. The main issue is that in the course of incineration a smoke containing toxic gases (dioxins, furans, nitrogen and carbon oxides, etc.) is formed. Separate waste collection with subsequent processing of the sorted materials is often technically unfeasible and economically unprofitable due to the high costs of materials, transportation, and human resources. Therefore, to reduce the anthropogenic impact on the environment, it is necessary to apply an environmentally friendly method of waste disposal – biodegradation (decomposing pollutants by such living organisms as bacteria, fungi, algae, etc.), that also provides production of certain valuable industrial products (biofertilisers, biogas, etc.) [38, 39].

This section discusses the results of screening microorganisms capable to biodegrade hard-to-degrade substrates (lignocellulosic raw materials, plastics), and also explores the potential of their using to process household waste into environmentally friendly products in a system with enclosed metabolism and energy cycles [8].

A. Concept Presenting

Biological degradation of wastes can occur under aerobic and anaerobic conditions. Composting is the process of decomposition of organic wastes, which is carried out by a consortium of aerobic microorganisms, into humus or compost, resulting in a decrease in the volume of waste, its decontamination, and obtaining biofertilisers with a high nutrition content. During anaerobic (oxygen-free) decomposition of MSW, biogas is produced, which is considered as a high-quality source of energy [38, 39].

The biodegradation of pollutants requires the presence of three key elements: the microorganisms selectively effecting the materials, the materials themselves, and the necessary environmental conditions. If one of these elements is absent, then biodegradation does not occur.

The process of waste biodegradation is strongly influenced by the environmental conditions (humidity, temperature, availability, and accessibility of nutrients, aeration, acidity of the environment) determining the vital activity of microorganisms. A significant change in the ambient temperature leads to decreasing activeness of the microorganisms and their transition into a state of suspended animation [40].

The use of microorganisms' associations, including strains-decomposers of a wide range of pollutants, is a relevant and promising direction of environmental biotechnology [41–43].

B. Objects and Testing Methodology

A bank of agronomically valuable groups of microorganisms, including microbial cultures isolated from the natural sources of various soils and climatic zones and having a set of useful properties, has been created in the agrotechnical research laboratory at Unitsky String Technologies Inc. [44] The microbial associations presented in the laboratory collection of microorganisms were used to study and optimise the process of MSW biodegradation.

A promising consortium of cellulolytic bacteria (No. 3), isolated from fertile soil sampled in Minsk Region (Belarus), under the laboratory conditions, showed the ability to grow in a nutrient medium [40] containing a wide range of lignocellulose compounds (carboxymethyl cellulose – CMC), sawdust, waste paper or fi - ter paper in a concentration of 1 %), and polythene film (polythene bags) (Figure 4)

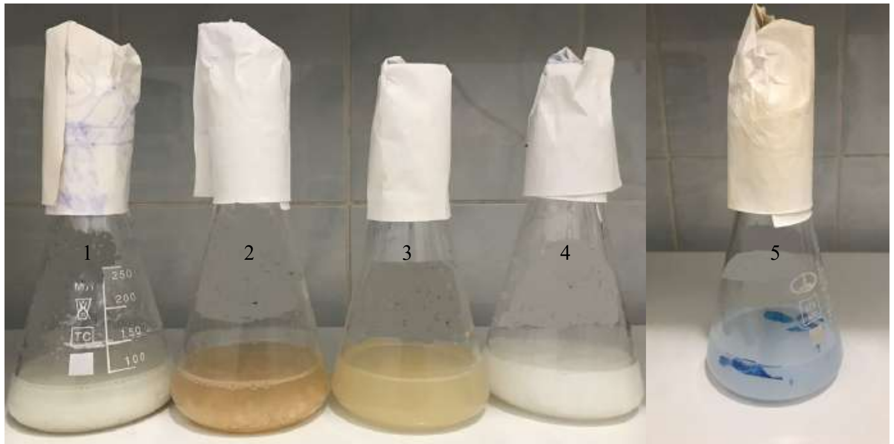

Figure 4 – Cultivation of the association of cellulolytic bacteria (No. 3) in a nutrient medium containing the following matters as a carbon source: 1 – waste paper; 2 – sawdust; 3 – CMC; 4 – filter paper; 5 – po ythene bag

To study the degradation potential of the selected microbial associations, an experiment was carried out on the biodegradation of household waste (food, cellulose and paper waste, plastics, glass), preliminary grinded with Champion SH250 garden electric grinder (China) to form particles with the dimensions of 1–5 cm. The MSW biodegradation process was studied in the autumn period under the aerobic (with mixing materials) and anaerobic conditions (without mixing) in a wooden box with a lid (45 × 70 × 25 cm) filled with the grinded waste treated with an inoculum of the studied microorganisms (Figure 5).

The constructed box has three sections. In the second section, the waste is processed under aerobic conditions. The wastes are mixed with the biomaterials and transferred from the first section of the system to the second one. In the third

section, the wastes are not mixed, and this allows creating the conditions close to anaerobic. The wastes are stacked into layers. The bottom layer contains grinded dry branches as drainage to remove excessive moisture and improve aeration necessary for the microbiological biodegradation processes. The next layer contains grinded MSW, and the top layer is a green mass of forbs (Figure 6).

Figure 5 – Construction of the wooden box for studying MSW biodegradation

a) b) c)

Figure 6 – Waste layers' composition in the experimental setup

C. Results and Analysis

After two weeks of the MSW experimental processing, the volume of wastes in the section with aerobic conditions decreased significantl . The wastes were actively decomposed by both native and introduced microorganisms.

After two months at the beginning of the experiment, the waste volume was reduced by half compared to its initial volume. In addition, there was no odor, and the green phytomass was completely decomposed. That indicates the biodegradation process efficiency. The results after two months of the degradation are shown in Figure 7.

Figure 7 – The waste biodegradation under the aerobic (b) and anaerobic (c) conditions after two months of the experiment

Under the anaerobic conditions, the process of waste bioconversion has a slower pace, as it was observed, while undecomposed plants and mineral residues participate in humus formation through low-solubility organo-mineral complexes highly resistant to the degradation. However, despite the structures complexity, humic compounds are processed to a certain extend over time by microorganisms, while enriching the substrate with nutrients accumulated in the humus, that allows it to be further used as an effective biofertiliser under the EcoCosmoHouse conditions, i.e., an enclosed ecosystem [43]. Together with electrohydraulically grinded brown coal introduced into the processed material, it is possible to reduce the concentration of MSW toxic substances (heavy metals, surfactants, etc.) and increase the content of nutrient components, thereby activating microbiological processes.

D. Conclusions and Further Research

The selected associations of cellulolytic microorganisms (No. 3), which has a complex of hydrolytic enzymes involved in the conversion of hard-to-degrade lignocellulosic and other substrates, is promising to accelerate the MSW decomposition and its transformation into humus-like components, which can be used as biofertiliser to increase soil fertility. The proposed microbiological method for processing MSW can reduce the volume of wastes and burden on the environment in comparison with traditional waste processing ways (incineration, burial) and allows obtaining an effective biofertilise .

In the future, it is planned to optimise the conditions for the process of MSW microbiological destruction, considering the selected associations of microorganisms No. 3 (the amount and timing of inoculum introduction, different degrees of MSW grinding, selection of the environmental conditions, mixing the substrate during the biodegradation process, etc.) and evaluate the efficienc of using the bioconversed product in the course of plants cultivation.

21.4 Application of Epibiotica Archaebacteria as Potential Microbiological Objects in Enclosed Ecosystems

In 1977 unique bacteria that differed in genome composition, structure, and habitat from common bacteria were discovered in the research works of American scientists K. Vese and G. Fox [45, 46]. These microorganisms were named archaebacteria (from Latin – *Archaea*, from ancient Greek – ἀρχαῖος "eternal, ancient, primeval, old"). The discovery was done based on the results of studying the molecular and biochemical properties of cells of various species of bacteria. Archaebacteria were validated as a distinct group because their sequence of nucleotides in 16S-rRNA was significantly different from other micro ganisms.

The main differences of archaebacteria are as follows [45, 46]

- there are no pathogenic or parasitic forms;
- these bacteria can feed on waste products of both micro- and macroorganisms, including humans;
- they occupy very unusual ecological niches unavailable for other organisms in the biosphere under extremal environmental conditions (water temperatures of up to 110 °C, pressure of tens and hundreds of atmospheres, high acidity (pH 1–5), environmental alkalinity (pH 9–11) or salinity with a mass salt fraction of 25–30 %) [47];
- archaebacteria are also distinguished by such certain genome features and cell structure in comparison with the true bacteria (eubacteria) as the absence of murein in the cell wall, excellent lipid structure of the cell membrane, cell morphology, the system of ribosomal protein synthesis, differenc between tRNA and genomic DNA, and similarity to the genome of eukaryotic organisms, unique biochemical and biosynthetic features of the group [45, 46].

Some scientists have an opinion that archaebacteria may be the firs living organisms on Earth when there was no free oxygen in the atmosphere, and active geothermal and volcanic activities were constantly occurring on the surface in connection with the release of sulfur vapor and overheated water with acids, salts or alkalis dissolved in it. Archaebacteria being extremely thermophilic, halophilic, and acidophilic had adapted to such conditions.

The above-mentioned properties allow the safe use of archaebacteria in the EcoCosmoHouse – an enclosed biological system with a full cycle of substance transformation [8] and waste recycling of various types [48–54].

Based on the above ideas, the authors of the section regard the study of possibility to apply extremophile microorganisms in the enclosed ECH biosphere [8] from the point of organic waste biorefinery as a promising research direction. The object of this work is to study the application of the archaebacteria unique abilities such as growth in extreme environmental conditions, life upon the lack of oxygen, production of organic substances using different compounds, including compounds of inorganic sulfur. The development of technology for the archaebacteria using in the isolated cycles as a source of new biologically active compounds, proteins, enzymes, exopolysaccharides, as well as biodegradants in ECH has also a scientific interest

A. Archaebacteria Classification

According to the second edition of the Bergey's Manual of Systematic Bacteriology [55], a system which is based on comparing the sequence of nucleotides in 16S-rRNA is used for classification of prokaryotes. In this manual, the classific -tion of prokaryotes also includes their genomic structure in combination with phenotypic features. According to the manual, prokaryotes are classified as the domains *Bacteria* and *Archaea* [55].

In accordance with the most recognized and used classifi ation presented in the ninth edition of the Bergey's Manual of Systematic Bacteriology [56], bacteria are divided into four sections: *Grafilicutes* – gram-negative eubacteria; *Tenericutes* – eubacteria without a cell wall; *Firmicutes* – gram-positive eubacteria; *Mendosicutes* – archebacteria, which cell walls are fundamentally diff rent from similar structures of other prokaryotes (the cell wall does not contain murein).

Nowadays, archaebacteria include extreme thermophiles, thermoacidophilic mycoplasmas, extreme halophilic bacteria, methanogenic, and anaerobic sulfur-reducing bacteria that metabolize molecular sulfur, as well as some poorly studied non-cultured thermophilic archaebacteria [45, 46].

Archaea classification is presented in Table 2.

Among these groups, methanogenic bacteria and halophilic archaebacteria, which have a unique ability of non-chlorophyllic photosynthesis, have the highest research interest to the authors. Some scientists regarded it as a saved ancient from of photosynthesis based on light-dependent transformations of carotenoid pigments [45, 46].

Extremophile microorganisms are used in the industrial biotechnology as a source of new biologically active compounds, proteins, enzymes, and exopolysaccharides with unique properties. Acidophilic sulphate-reducing microorganisms and alkaliphilic microorganisms have found their application in the industrial biotechnology. For more than a decade, methanogenic bacteria have been used in special bioreactors to produce methane from animal waste [51–54].

Table 2 – Archaea classificatio

Taxon	Name		
Superkingdom (domain)	*Archaea*		
Phylogenetic branches	*Crenarchaeota*	*Euryarchaeota*	*Korarchaeota*
Groups			
Methanogenic archaebacteria: genera *Methanobacterium*, *Methanosarcina*, *Methanospirillum*, *Methanobacillus*, etc.			
Anaerobic sulphate-reducing (sero-reducing) archaebacteria: genus *Archaeoglobus – A. fulgidus*, *A. profundus*			
Extremely thermophilic and hyperthermophilic archaebacteria that metabolize sulfur: genus *Sulfolobus – S. brierley*, family *Thermococcales*, family *Thermoproteales,* genera *Acidianus*, *Pyrodictium – P. occultum*			
Archaebacteria without cell walls (thermoacidophilic mycoplasmas): *Thermoplasma acidophilum*			
Extremely halophilic archebacteria (halobacteria): genera *Halococcus*, *Halobacterium*, *Haloarcula*, *Natronobacterium*, *Natronococcus*			
Understudied nonculturable thermophilic archaebacteria			

B. Method Description

Cultivation of Archaebacteria

Most of archaebacteria can't be cultivated under the ordinary conditions. Therefore, this domain has not been fully studied regarding the laboratory cultivation until now. The cultivation of bacteria is connected with creation of the specific conditions for their growth and activities: almost complete lack of oxygen, compound nutritional mixture, special temperature, and lightning conditions. For a long time, people have been using the properties methanogenic archaebacteria in practice under the ordinary conditions. Anaerobic conditions are created in special airproof bioreactors, where a mixture of organic waste and water is placed, due to the bacteria processing of oxygen and beginning of fermentation processes. During the fermentation, the following chemical substances are accumulated: organic acids, carbon dioxide, hydrogen, and alcohols. These products inhibit fermentation. The process would stop if these substances were not substrates for archaebacteria. At this stage, the addition of methanogenic archaea allows completing the process of oxygen-free biodeterioration of the organic elements. The activity of methanogens can be described with the general formula: $CO_2 + H_2O \rightarrow CH_4 + 2H_2O$.

Experiment Implementation

It was planned to study the experimental data on methanogenic bacteria activity in the conditions of an underground collector built under the house located at Unitsky's Farm Enterprise. This type of construction can be referred to an anaerobic wastewater purifie .

There is a mechanical supply of air or technical oxygen to the bottom of the aerotank in anaerobic purifiers

Anaerobic treatment is a fermentation of highly concentrated wastewater, carried out by microorganisms in the absence of oxygen (under the anaerobic conditions) with the formation of combustible biogenic gas. Biogenic gas is a mixture consisting of 65 % of methane, 30 % of CO_2, 1 % of H_2S, 4 % of N_2, O_2, H_2, and CO (carbon monoxide) mixtures [52]. The formation of biogenic gas is based on the methane fermentation process or so-called biomethanegenesis.

The prevailing groups of microorganisms in the methanogenic cenosis are: hydrolytic, fermentative, syntrophic, and methane. They successively carry out the stages of anaerobic fermentation. There are relationships between groups of these microorganisms. The development of methanogens depends on the bacteria of the previous stages and the substrate features.

According to the number of species in the methanogenic cenosis, the ordinary anaerobic fermenting bacteria (eubacteria) prevail: their quantity is 10 times higher than methane-generating bacteria. About 30 out of 300 species of anaerobic microorganisms generate methane [52].

In the methanogenic biocenosis, close symbiotic relationships between various microorganisms present, a consistent fermentation of organic substance takes place, and the waste products of some bacteria are substrates for others.

Many bacteria do not participate in the biodegradation of organic substances but they can release growth factors or remove toxic metabolic products of other bacteria from the system.

Facultative anaerobes in the methanogenic cenosis can use accidentally released oxygen, thereby maintaining strict anaerobic conditions, because oxygen inhibits the metabolism of methanogenic bacteria.

Methanogenic bacteria vary morphologically, however, they have two common characteristics:

- they are obligate anaerobes;
- these bacteria can generate methane.

All methane-generating bacteria belong exclusively to archaebacteria [52].

There are more than 45 species of methanogens which are classified among 13 genera: *Methanobacter*, *Methanococcus*, *Methanogenum*, *Methanosarcina*, *Methanothrix*, and others. Methanogenic bacteria always live in a complex microbial cenosis, where they perform the last stage in decomposing complex organic substances.

Other members of the cenosis carry out the preparatory stages for methanogenesis:

- fermentation of monomers to organic acids, alcohols;
- conversion of acids and alcohols to acetate, CO_2, H_2.

One-third of methane-generating bacteria receives energy in the process of oxidation of hydrogen, which is the electron source, while a conjugate reduction of carbon

dioxide takes place. According to the nutrition type, they are characterised as chemoautotrophic methanogens: $4H_2 + CO_2 \rightarrow 2H_2O + CH_4$.

Two-thirds of methane are generated by the conversion of acetate (acetic acid): $CH_3COOH + 2H_2 \rightarrow CH_4 + 2H_2O + 3CO_2$.

More than 70 % of methane is generated from acetate during the anaerobic decomposition of complex organic substances.

Methanogenic bacteria convert 90–95 % of the used carbon into methane, and only 5–10 % of the carbon is spent on biomass growth. The intensity of anaerobic conversion of organic substances into methane depends on the following:

- the rate of biopolymers hydrolytic digestion (if they are abundant in the processed raw materials);
- the rate of transformation of acetate into methane is associated with the syntrophic and methanogenic bacteria low growth and reproduction rates.

The time for doubling the hydrolytic microorganisms biomass is 10–20 hours, as for acidogens – 1–10 hours, syntrophic (acetogenic) bacteria – about 100 hours, methanogens using hydrogen – 15–100 hours at 35 °C. The anaerobic treatment facilities include septic tanks, humus tanks, contact tanks, anaerobic lagoons, methane tanks, and trickling filters

The general scheme of processes taking place during the anaerobic fermentation in wastewater treatment systems is shown in Figure 8 [52].

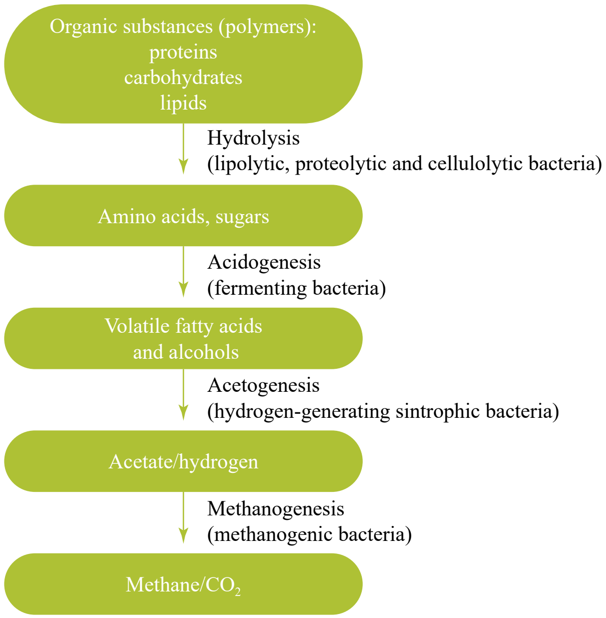

Figure 8 – Scheme of processes taking place during the anaerobic fermentation (methanogenesis)

Typical examples of anaerobic treatment facilities are septic tanks, common facilities in individual households. Septic tanks work independently and do not need an external power supply. Septic tanks are used when the amount of incoming water does not exceed 25 m^3 per day.

Septic tank consists of two parts (Figure 9).

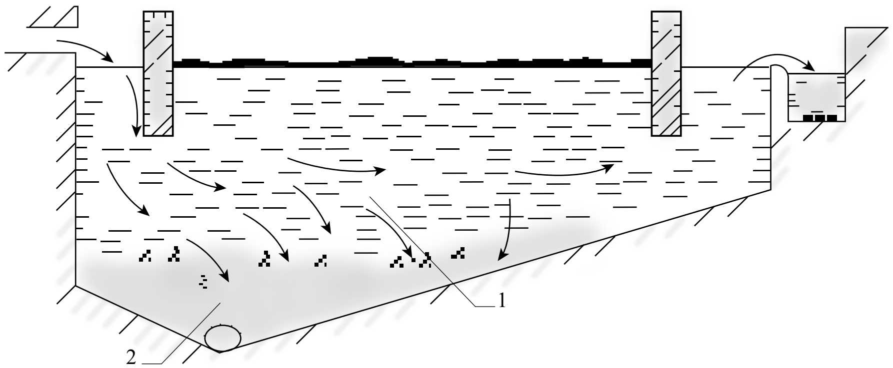

Figure 9 – Septic tank: 1 – nettling part
(to perform water clarification due to its movement at a low sp ed);
2 – septic part (located under the first section,
where the sludge is digested when being stored for 6–12 months)

The water is in the septic tank for 3–4 days.

When organic substances decompose, the sludge volume becomes more compact. The silt is periodically removed (usually once a year). Part of the silt is left to maintain the work of the septic tank.

Most of septic tanks work without heating at a temperature of less than 20 °C.

Thus, the study will be conducted in the collector of house No. 12 serving as a mini-hotel on the basis of Unitsky's Farm Enterprise.

The collector is an underground can which walls are penetrable by plant-roots. It is located in the subtropical garden inside the house at a depth of 2 m, where flows from the sanitary accommodations (seven separate units) and kitchen (including the washing machine and dishwasher) are gradually absorbed by the filtering organics layers where the organic substance of wastewater is being decomposed until it becomes completely mineralized. At the top, the collector is covered with fertile soil, where purified water with mineral salts is absorbed from below through the root system and soil capillaries (Figure 10). Excessive water comes to an external containment pond through the external sewer system.

The research was planned to be conducted in two stages. At the firs stage, it was planned to study microbiological parameters of the wastewater samples from the collector assess the necessity of artificial bacterial contamination of the collector with methanogen bacteria if natural contamination did not happen.

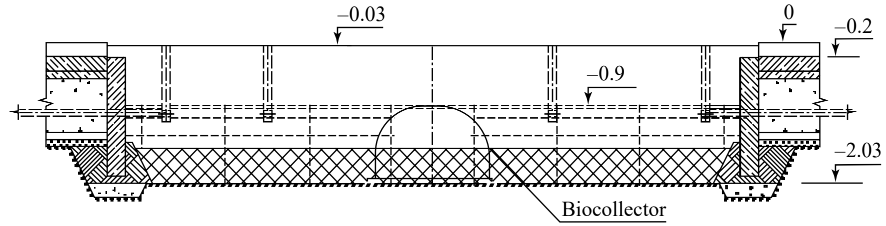

Figure 10 – Scheme of the domestic biocollector

The primary results demonstrated a significant decrease of bacterial contamination in the water from the collector outlet unit in comparison with the wastewater inside the collector (Table 3).

Table 3 – Microbiological parameters of the samples from the collector

Sample number	Place and date of sampling	Quantity of microorganisms in 1 ml
1	Wastewater from the sewer that flows to the collector can (sampling on 30.04.2020)	1.5 × 10^{10} CFU/ml
2	The collector under house No. 12, the central can (sampling on 30.04.2020)	1 × 10^9 CFU/ml
3	The collector under house No. 12, emergency release hatch (sampling on 01.06.2020)	5 × 10^5 CFU/ml
4	The collector under house No. 12, emergency release hatch (sampling on 07.07.2020)	1 × 10^6 CFU/ml

Table 3 shows that there is a consistent decrease in the quantity of bacteria by 150 times for the first time, and then by 1,000–2,000 times. Such a significant decrease indicates successful water purification, because the mineralization of organic substance due to its decomposition causes a lack of food resources for putrefactive and fermenting bacteria and, as a result, a decrease of their population.

At the second stage, it was planned to bacterized the house collector with the developed culture of methanogenic archaebacteria and continue the research. The main parameter of the efficiency of both organic destructor bacteria and methanogenic bacteria will be the index of biological oxygen demand or bacterial oxygen consumption (BOC) which is used to assess the intensity of bacterial growth and reproduction and, consequently, as an efficienc factor of wastewater treatment and destruction of organic substance. This index will also imply the methanogenic bacteria activity.

C. Conclusions and Further Research

The authors have regarded such a domain of microorganisms as archaebacteria having unique characteristics in comparison with ordinary bacteria and living in the extreme environmental conditions of underground geothermal hot springs, in ultra-saline, acidic or alkaline waters, as well as in the depths of peat bogs, silt at the bottom of reservoirs, sewage treatment facilities, and the digestive tract of herbivores.

Such a variety of environmental properties of this group of microorganisms allows us to consider them as a promising direction for establishing the closed cycles inside ECH. It is planned to analyse industrially used microorganisms of this group, as well as to conduct a search for them in the native environment in order to create a collection of archaebacteria strains, lay the basis for biogas production by methanogenic archaebacteria using a bioreactor, study the potential of these strains for appliance in ECH.

The conducted microbiological research of the biological collector built under the house on the basis of Unitsky's Farm Enterprise holding has shown a significant reduction in bacterial contamination at the wastewater outlet unit, which may indirectly confirm effectiveness of water treatment from organic contaminants. This process is possible with methanogenic archaebacteria activity used at the last stage. Further research includes the collector microflora enrichment with a methanogens culture developed from natural sources and the study of changes in the microbiological contamination of treated water. At this stage the indicator of biological oxygen demand will be also studied, that will directly indicate the effectiveness of wastewater treatment and destruction of organic substance by the microbiocenosis with the methanogenic archaebacteria.

Based on the above, it can be concluded that archaebacterial can be used in the isolated cycles within ECH, complementing the chain of organic waste processing; and due to the unique adaptive properties of this group of microorganisms, it is useful to study the possibility of their employment under the conditions connected with the establishment of the enclosed ECH systems in outer space.

There are no pathogenic species among archaebacterial, and their life activity is not associated with the production of compounds toxic for humans. Herewith, this way is deemed to be environmentally friendly that is a priority factor for ECH. ECH is an enclosed system, and the use of relict archaebacteria with unique properties will provide a higher level of maintaining the ecological balance, as well as improve the safety of technologies for organic waste bioprocessing.

21.5 Developing Soil Composition for Enclosed Ecosystem in Outer Space

In the residential space cluster of "EcoCosmoHouse", it was planned to create conditions that will be comfortable for people to live in, and also to simulate the corresponding parameters of an enclosed biosphere for sustainable coexistence of flora and fauna, including microflora and microfauna. A vital criterion is the formation of oxygen in an enclosed ecosystem of the ECH, which will be carried out

by the plants [57]. For comfortable living environment, plants need optimal temperature and humidity conditions, but the most important issue is the presence of fertile soil. In addition to its nutritional function, the soil is a habitat to thousands of species of microorganisms, small soil animals, and fungi without which the existence of plants is impossible.

It is known that the main organic matter of the soil, i.e., its most fertile component, is humus containing humic substances which are necessary for plants' development and growth [58]. The results published in the literature confirm the possibility of replacing the infertile part of the soil with lighter materials such as perlite [59–62], expanded clay [63], pumice, and others, while the function of the fertile component will be performed by UniTerra component containing the necessary humic substances and beneficial soil-based microo ganisms [59, 64].

The task that this study aims to solve is to create a "space" soil that has a number of advantages in comparison with conventional soil, namely:

- reduced weight;
- increased water absorption and impact resistance;
- low cost;
- increased nutritional value for effective growth and developmen of plants;
- content of the whole range of ultra-, macro- and microelements which are necessary for the life support.

A. Selection of the Components of the "Space" Soil

According to pedology science, there are mineral and organic components of soil. The mineral part of soil is resulted from the rocks weathering and accumulation of particles having various sizes which have been mechanically mixed under the impact of gravity, wind, and water. The mineral part makes up 80–90 % of the overall soil weight, with the exception of organogenic soils where its percentage can decrease to 10–15 % [65].

On the basis of publications [59–61, 63], the authors of this section suggest replacing the soil mineral part (80–90 % of its weight) with lighter minerals that allow forming the required structure of the substrate (Table 4).

As it is seen from Table 4, as an alternative replacement for the soil mineral part, only natural and ecologically pure minerals were considered, such as perlite, vermiculite, expanded clay, shredded bark, and coconut substrate containing the majority of the elements of the periodic table. In addition to the criterion of environmental friendliness of the used materials, their characteristics were considered, such as the size of fractions, density, water absorption, cost, and, most importantly, the content of minerals necessary for the plants to grow on this soil.

The size of the fractions is important to form the necessary soil structure, i.e., a very small fraction (less than 1 mm) forms dust and dirt, and will have a larger weight when poured in a thick layer. At the same time, the use of large fractions (20–50 mm) is not suitable because through such large mineral fragments the finely dispersed organic soil layer will be washed out during irrigation.

Table 4 – Characteristics of substitutes for the soil mineral part [66–69]

Foamed mineral name	Description	pH	Fraction size, mm	Estimated cost, USD/m³*	Bulk density, kg/m³	Water absorption, %
Perlite (agroperlite)	Expanded product of grinding and heat treatment of volcanic rock	7–7.5	1.5–5	37.6	65–232	100–1,000
Vermiculite	Expanded layered mineral	6.8–7	2–4	100.4	65–130	400–530
Expanded clay	Molded and foamed fired cla	7	1–4	96.2	350 (depending on fraction composition. Granule size: 20–40 mm)	15–25
Shredded bark	Shredded bark of coniferous trees	< 7	0–10 10–30	33.5 54.4	100–600 (depending on fraction composition and wood species)	140–200 (depending on fraction composition and wood species)
Shredded pumice	Volcanic rock	7–8	1–3 5–8 15–25 30–50	719	450–750	11–17
Coconut substrate	Shredded and pressed coconut shell	5.8–6.5	Briquettes, mats of various shapes	418	330	700–900

* Cost of materials is provided for reference purposes and will largely depend on the supplier and scope of delivery.

Such a material characteristic as its density allows calculating its weight for a certain volume. It is known that the density of ordinary fertile soils depending on their type varies between 1,100–1,700 kg/m³ [65]. At the same time, the density of perlite is only 65–232 kg/m³. Thus, replacing a mineral soil layer with a height of 1 m with density of 1,500 kg/m³ with a layer containing 90 % perlite will decrease the overall substrate weight by 4.2–7.2 times.

From the reference [57] it is known that the estimated mass of fertile soil, which will be placed in ECH for 5,000 people, will be around 200,000 tons.

Thus, by reducing the volumetric weight, significant savings can be achieved in the costs of the soil components delivering from the planet to the orbit.

Water absorption means the ability of a substance to absorb and retain water in pores and capillaries. It is an important parameter for the "space" soil. The higher this indicator is for a given material, the more it is able to bind water and keep it inside the structure for a longer time. Due to this property, there will be a gradual release of water being consumed by plants. Thereby, it will reduce the required watering frequency. According to this criterion, such material as perlite has the highest value of this parameter and depending on the size of the fraction is capable of retaining water in an amount of 100–1,000 % of its dry weight.

Perlite has the lowest materials cost considered in Table 4 that is another advantage for its use in the composition of the "space" soil for ECH.

Scientific publications devoted to the use of perlite in agriculture [60, 61] describe its following positive qualities:

- allows solving the problem of watering plants in arid regions;
- makes soil loose and breathable;
- plays a catalytic role in oxidative processes occurring in soil;
- helps to reduce soil acidity;
- residual decomposition doesn't emit by-products polluting the surrounding area [62].

The authors of the reference [63] studied the possibility of using expanded clay (3–5 mm) as a substrate for growing tomatoes in the open field. In this case, the soil was not used. Plants' nutrition was carried out with various doses and compositions of nutrient solutions.

It was found that the main compounds of expanded clay substrates, as well as of the soil mineral part, are oxides of silicon – 55.3 %, aluminum – 16.9 %, and iron – 10.5 %. Expanded clay, along with perlite, contains microdoses of almost all chemical elements from the periodic table, which can be "extracted" by microorganisms for plant nutrition. Over the five years of using these root-inhabited media, the total content of silicon and iron oxides decreased by about 2 %, the total content of aluminum oxides over this period, on the contrary, increased from 16.9 % to 18.4 %. This is due to the gradual destruction of the substrate structure [63]. The data obtained by the authors allowed concluding that it is possible to use expanded clay in the composition of soil without replacing it during the entire lifetime of ECH.

Thus, the authors propose to use perlite and expanded clay as replacements for the mineral part of soil, just like their mixture (size of fractions of up to 1–4 mm) but without using hydroponics techniques.

The organic part of soil is formed by dead scrap of plants (their ground and underground parts), microorganisms, and micro-animals in different stages of decomposition and humification, as well as humic acids and their salts [60]. As a replacement for the soil organic part, it is proposed to use UniTerra composition created on the basis of processed brown coal and humic-containing substances, along with soil microorganisms. All of these components are a prerequisite for creating highly fertile soil [59, 64].

B. Description of Planned Experiment

The planned experiment is aimed to research the influence of the developed "space" soil on the plants' growth and development. The tasks that the authors set themselves are as follows:

- to select the light mineral soil components;
- to select plants to grow in the "space" soil for study;
- to research the influence of the "space" soil on the plants growth and development.

Perlite, expanded clay, and their mixture will be used as the soil mineral part. The added components should reduce the weight of the soil, but at the same time increase its impact resistance, reduce cost, be environmentally friendly, and contain the necessary set of microelements. The organic part was replaced by UniTerra composition.

The authors proposed a design of three high beds. The internal size of each is 1,500 × 700 × 1,000 mm (height × width × length) with a total volume of 1.05 m^3. Artificial lighting will be placed above the beds that is necessary for the plants' development, and watering will be adjusted manually.

Medicinal and fruit plants proposed for planting in high ridges are given in Table 5.

Table 5 – Conditions for growth and development of the proposed plants

Name plant	Temperature, °C	Humidity, %	Vegetation period
Melissa	18–22	50	All year round
Lavender	18–22	50	All year round
Mint	20–25	50	All year round
Thyme	20–25	50	All year round
Aloe	20–25	40–60	All year round
Kalanchoe	20–25	40–60	All year round
Lemon	18–25, at least 6 hours of sunlight	50	Spring – autumn
Mandarin	16–30	60	Spring – autumn
Kumquat	25–30	60	Spring – autumn
Perennial pepper	20–25	60	Spring – autumn
Grapefruit	20–27	50–60	Spring – autumn

The plants have been chosen according to the following criteria: a year-round vegetation period or the ability to bear fruit, temperature regime of 20–25 ℃, humidity of 40–60 %, fruits, leaves, or roots of plants are edible (trees, shrubs, vegetables, etc.) or it is possible to use parts of them to brew herbal tea (medicinal plants).

Fruit trees such as apple trees, pears, plums, and others are subject to seasonal changes such as foliage shedding and transition to a dormant period, so, they are not included in the experiment. As an alternative, indoor citrus trees were chosen, which, although they have seasonality of flowering, do not shed their foliage and remain green all year round, that is an important psychological factor for the relaxation of persons living in the enclosed ECH environment [70, 71].

The placement of plants in high beds depends on the size of the crown, as well as the thickness of the stem at the root collar. For example, the seat for a lemon tree having a crown with a diameter of 40 cm should have the same size. Therefore, two citrus trees and one medicinal plant can be planted in one garden bed, in a single layer. Considering the need to save the space in ECH, it is possible to plant mini-trees in two tiers (Table 6).

Table 6 – Selection of plants for planting in high ridges

Bed number	Soil composition	Plants
1	Perlite + UniTerra	Trees*: 1st tier – mandarin; 1st tier – kumquat; 2nd tier (higher) – lemon; 2nd tier – lime. Herbs**: saxifrage
2	Expanded clay + UniTerra	Trees: 1st tier – calamondin; 1st tier – meyer's lemon; 2nd tier – bergamot; 2nd tier – citron. Herbs: yagel (deer lichen) or creeping thyme
3	Expanded clay + perlite + UniTerra	Trees: 1st tier – citrofortunella; 1st tier – japanese mandarin; 2nd tier – limonella; 2nd tier – grapefruit. Herbs: micromint

* When planting two trees in a garden it is suggested to choose variants from four plants.
** The proposed herbs are groundcover (up to 15 cm) and have medicinal properties.

During the experiment, it is necessary to collect data about the following conditions: temperature, humidity, illumination, and additional watering.

The results obtained will be used to organise the beds where it is planned to grow various plants, including fruit, using the developed "space" soil.

For the preliminary experimental verifi ation of the possibility of using the “space” soil as a substrate for the plants’ growth and development, the following experiment was carried out (Figures 11a, 11b). The “space” soil was prepared, it contained 97.5 % of perlite and only 2.5 % of UniTerra composition (Figure 11a). Even with such a low content of the soil organic component, the unpretentious plant got rooted. However, in Figure 11b, it can be seen that the plant root hairs have reached the bottom of the tank that is probably due to the downward migration of the soil organic part because of its washing out with the water means.

a) b)

Figure 11 – Plants growth in the “space” soil: a – general view; b – close-up

Therefore, to study the process of washing out of the organic part of the soil, two more compositions of the “space” soil were prepared, containing 10 % (Figures 12a, 12b) and 20 % (Figures 12c, 12d) of UniTerra component. The smallest washing out of the soil organic part was observed at 20 % UniTerra concentration, 10 % UniTerra takes an intermediate position. It should be noted that an important advantage of using 10 % UniTerra is the reduction in the soil total weight soil as compared to the 20 % UniTerra content.

On the basis of the preliminary experiment, the calculation of the necessary materials for various composition options of the “space” soil was made, considering that UniTerra soil occupies the pore volume between the mineral components. The calculation results are presented in Table 7.

a) c) b) d)

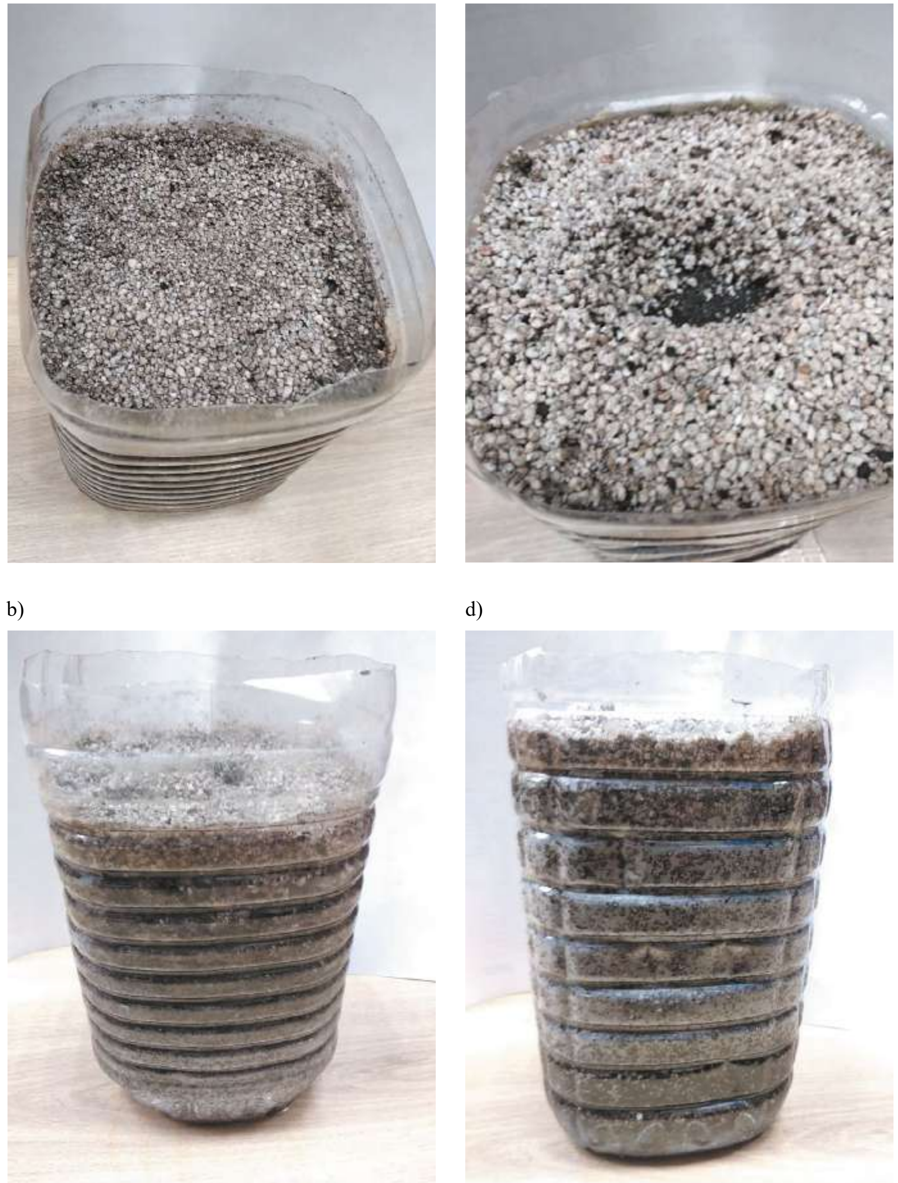

Figure 12 – Options of the “space” soil with different concentr tions of the mineral part and UniTerra: a, b – 10 % of UniTerra; c, d – 20 % of UniTerra

According to these calculations, the “space” soils will be prepared to study their influence on the plants’ growth and development, as demonstrated in Tables 5, 6.

Table 7 – Quantitative characteristics of the "space" soil components

Bed number (options)	Mineral part type	Density of mineral parts, kg/m^3	Weight percentage of mineral parts, %	Weight of mineral part, kg	Volume percentage UniTerra, %	Weight of UniTerra, kg	The total weight of the "space" soil for one high bed, kg
1	Perlite	65	90	68.3	10	105	173.3
1	Perlite	149	90	156.5	10	105	261.5
1	Perlite	232	90	243.6	10	105	348.6
2	Expanded clay	350	90	367.5	10	105	472.5
3	Perlite + + expanded clay	65 + 350	60 + 30	166.8	10	105	271.8
3	Perlite + + expanded clay	149 + 0.35	60 + 30	225.6	10	105	330.6
3	Perlite + + expanded clay	232 + 350	60 + 30	283.7	10	105	388.7

C. Conclusions and Further Research

The section discussed physical, mechanical, and agronomic properties of the developed soil compositions. The selection of light mineral soil components (perlite, expanded clay, a mixture of perlite, and expanded clay) has been performed. The plants have been selected for planting in the "space" soil; they have seasonal flowering but do not shed their foliage and remain green throughout the yea .

Based on the foresaid, it can be seen that the authors theoretically substantiated the creation of the "space" soil consisting of light mineral fillers (in comparison with ordinary soil) and an organic part – UniTerra composition. In terms of the totality of its properties, the developed soil can be effectively used in ECH, since it has high fertility and low density. Thus, the need for the delivery of heavy soil to ECH for a thickness of several metres disappears, that will give a significant econ mic effect

Further activities are seen by the authors in conduction and analysis of the experimental results showing the possibility of using the "space" soil for the effective growth and development of medicinal, fruit, and berry plants.

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22

Some Aspects of Maintaining Enclosed Ecosystem in Healthy State

22.1 Lake Water Purification with Mineral Additives

Environmental pollution problems are growing in importance annually with development of technosphere and active industrial activities of the mankind. Contamination of surface and groundwater on the planet requires development of new purification methods and improvement of existing ones which can be used for various chemical decontamination [1]. Water purification has become a common practice all around the world, but the majority of the employed technologies require significant space and energy investments. In particular, large filtration fields are used for wastewater treatment, and filters with sophisticated replaceable cartridges are used for drinking water production.

Creation of enclosed ecosystems requires introduction of innovative purific -tion methods that have to comply with renewability, efficien , and eco-friendliness requirements. Hence, applied methods should not disturb the ecosystem balance [1, 2]. Self-cleaning process is based on gradual recovery of the water system's typical eco-structure and biodiversity after penetration of the alien pollutants [3].

Water organic pollution is a major problem regarding normally functioning of aquatic ecosystems [4]. The results achieved during the present research will be helpful in the course of the EcoCosmoHouse on Planet Earth (ECH-Earth) establishment which will serve as a prototype of future human space colony [2].

The research aim is to investigate ways providing water purification by its continuous circulation through filtering additives that are mixes of d fferent minerals [2, 3]

The following tasks were implemented during the research process:

- selection of the optimal mineral additives composition;
- determination of the required speed and time for water passed through the additives;
- estimation of the additives effective operation time
- estimation of water volumes filtered through the additives
- evaluation of possible methods for various microbial stains purification

A. Minerals Used for Natural Water Purification and Their Properties

Natural compounds were selected because of their molecular sieve effect in order to study the ability of mineral substances to purify water from organic and inorganic impurities, as well as mineral additives for lake water treatment were chosen subject to information of the previous researches [5–8]. Herewith, the reviewed natural minerals include gravel, flint, a gillite, quartz, schungite, and jadeite.

Flint consists of cryptocrystalline quartz (i.e., chalcedony), opal, iron hydroxides, glauconite, and carbonates [9]. As a result of its interaction with water, it inhibits putrefactive bacterial growth and removes from the water compounds of heavy metals such as zinc, lead, cadmium, iron, and mercury. It also neutralizes chlorine and nitrate compounds, as well as sorbents radionuclides [9, 10].

Gravel (quartz) is a filtering material with a high content of silicon oxide (up to 99 %) and a minimum amount of soluble calcium, iron, and manganese compounds. It is highly resistant to mechanical and chemical influences. Gravel is used as a layer retaining organic elements [8].

Rock quartz silicifies water. This element provides bone tissues with flexibility and elasticity, nails and hair with strength, as well as it supports rapid tissue regeneration [10, 11].

Schungite and jadeite offer absorbent properties and fi l water with such mineral elements as Mg^{2+}, K^{+}, Ca^{2+}, Na^{+}, Mn^{2+}, Ba^{2+} [9, 12], along with normalizing ionic exchange between them. This is essential for the elements' absorption by the organisms [11].

Zeolites release and absorb water depending on temperature and humidity. They are also capable of ionic exchange. This process serves as a basis for releasing and absorbing particular substances and performing cations exchange [13].

In addition to minerals, charcoal is also needed. Thanks to its high sorption capacity, it easily removes organic components from the water [7, 8, 14].

Based on the above, we can conclude that the use of the abovementioned minerals provides primary water purification from organic substances, as well as its saturation with various ions that is essential for all living organisms.

Nowadays there are many devices for water purification from insoluble particles and impurities. Different types of filters use the minerals described above, but on a standalone basis [6, 7]. Not all existing methods are suitable to implement in the enclosed system for the reasons that they are non-renewable (because of continuous cartridges replacement) and require large areas for their efficien operation (for example, filtering fields). There is no research on water treatment in an enclosed environment in the world. Most of the developments are intended for water treatment in Africa regions. This section is aimed to create a system for purification of large water volumes in the enclosed ecosystem with the use of different minerals and materials.

B. Experiment Description

It is impossible to prevent ingress of various endogenous compounds into the general water mass circulating in the enclosed ecosystems. Therefore, a cleaning solution should be developed subject to the ability of the minerals to sorb contaminations of different types

At the same time, one of the basic needs is clarification of drinking water. Sanitary Rules and Norms (SRN) estimate the chemical constitution of drinking water, including the content of different substances [15]

It is necessary to monitor content of calcium (that alkalizes soil) and chlorine (that destroys cells) in the water for plants showering. Other indexes specifi d in the SRN are not so important to plants.

The purity indexes of water intended for animals' needs should be the same as for humans, although some excess in amount of certain macro- and microelements is allowed. However, the bacteria titration should strictly comply with the SRN (total microbial number should be no more than 50 colonies in 1 cm^2 [8, 14, 15]).

Composition of water for household uses is regulated by lower chemical composition standards, but it is necessary to control its hardness and quantity of organic substances according to the specific SRN

Figure 1 shows the mineral loading scheme for water purification which was developed in the course of the present research.

Figure 1 – Mineral loading scheme

The scheme includes:

- charcoal (replaceable component that provides a month of continuous use) makes up to 20 % of the mineral additives total volume;
- coarse minerals (fl nt, mountain quartz, schungite, and jadeite) which form special associates during their interaction with water such as colloids absorbing harmful impurities and microbiota from the environment (their amount is equal to 20 % of the total loading volume);

- fine minerals (zeolites, gravel, sand), thanks to their fineness are capable to catch various types of contaminants (their amount is equal to 30 % of the total loading volume);
- method of water purifi ation with the use of banana peel is good to purify water from heavy metals and gives it a pleasant taste (substance amount makes up to 15 % of the total loading volume);
- activated carbon is used to remove residual organics (it composes 15 % of the total loading volume) [14, 16, 17].

Figure 2 shows the developed structure to provide efficien mineral loading placement in the process of water purification. The design represents spiral-shaped PVC 110 mm diameter pipes deployed with a slope of i = 0.001. The pipes are fix d on a wooden base. There is a semi-permeable partition at the end of each pipe section in order to retain the mineral part there. The total length of the water filtration path is 26.4 m.

Figure 2 – Structure for water purificatio

There were passed 50 l of the lake water through the developed system. The lake water contains a large number of organic substances, as well as various chemical compounds. The water volume is determined according to the banana additives' useful lifetime. First water amounts wetted the device surface and minerals pores and the next ones were purified during their pass through the p pes.

C. Results and Discussion

Four water samples were taken in the course of the experiment. Sample No. 1 is the lake water. Sample No. 2 is the water taken after passing one full cycle in the developed purification device. Sample No. 3 is the water taken out after passing the first 20 l of water through the system. Sample No. 4 is the water taken out after passing 40 l of water through the system.

The obtained samples were sent to the Scientific and Methodical Testing Department of the Republican Unitary Enterprise "Scientific Practical Centre of Hygien" for their further analysis. The results are presented in Table 1. The analysis was carried out according to the basic requirements of the SRN in order to perform a more comprehensive study of the water composition at different stages of the purification process.

Table 1 – Test results of the water samples analysis obtained from the experiment

Indexes	Units of measurement	Technical regulations	Requirements		Sample No. 1 (lake water)	Sample No. 2	Sample No. 3	Sample No. 4
			SRN specified for non-centralised drinking water supply systems	SRN 10-124 RB 99 specified for centralised drinking water supply systems				
1	2	3	4	5	6	7	8	9
Turbidity	mg/dm³	GOST 3351-74	No more than 2	No more than 1.5	–	32.1	41.6	21
Colouration	Degrees	GOST 31868-2012	No more than 30	No more than 20	–	3	2	2
pH	pH units	ISO 10523-2009	6–9	6–9	8	9.9	9.8	8.8
Dry residues	mg/dm³	GOST 18164-72	No more than 1,500	No more than 1,000 (100–1,000)	208	3,068	1,375	487
Petroleum products	mg/dm³	Environmental regulations federal (ER F) 14.1:2:4.128-98	Not defined	No more than 0.1	–	–	–	–
Ammonia	mg/dm³	ISO 14911:1998 (E)	Not define	No more than 2	–	0.29	–	–
Permanganate oxidation	mg/dm³	GOST R 55684-2013	No more than 7	No more than 5	5.4	7.7	7.9	4.5
Total hardness	mmole/dm³	GOST 31865-2012	No more than 10	No more than 7 (1.5–7)	3.75	6.07	4.7	3.62
Calcium	mg/dm³	ISO 14911:1998 (E)	Not define	Not defined (25–130)	51.98	0.46	10.22	20.89
Magnesium	mg/dm³	ISO 14911:1998 (E)	Not define	Not defined (5–65	14.13	73.57	50.96	31.34

The continue of Table 1

1	2	3	4	5	6	7	8	9
Potassium	mg/dm³	ISO 14911:1998 (E)	Not define	Not defined (2–20	3.61	1,355.15	547.11	167.1
Sodium	mg/dm³	ISO 14911:1998 (E)	Not define	No more than 200	7.2	57.07	48.22	31.11
Sulphates	mg/dm³	GOST ISO 10304-1-2016	No more than 500	No more than 500	10.95	96.98	69.67	31.4
Chlorides	mg/dm³	GOST ISO 10304-1-2016	No more than 350	No more than 350	7.01	28.83	29.69	15.06
Nitrates	mg/dm³	GOST ISO 10304-1-2016	No more than 45	No more than 45	–	0.14	0.13	0.12
Nitrites	mg/dm³	GOST ISO 10304-1-2016	Not define	No more than 3	–	–	–	–
Phosphates	mg/dm³	GOST ISO 10304-1-2016	Not define	No more than 3.5	0.13	1.33	0.71	–
Fluorides	mg/dm³	GOST ISO 10304-1-2016	Not define	No more than 1.5 (0.5–1.5)	–	–	–	0.5
Bohr	mg/dm³	GOST 31949-2012	Not define	No more than 0.5	–	–	–	0.34
Silicon	mg/dm³	According to Yu. Novikov	Not define	No more than 10	1	3	2.45	5.3
Bicarbonates	mg/dm³	GOST 31957-2012	Not define	Not defined (30–400)	–	2,293.6	1,037	481.9
Total iron	mg/dm³	Measurement Technique (MT) 3057-2008	Not define	No more than 0.3	0.011	0.101	0.096	0.055
Manganese	mg/dm³	Measurement Technique (MT) 3057-2008	Not define	No more than 0.1	0.011	0.244	0.155	0.034

The end of Table 1

1	2	3	4	5	6	7	8	9
Zinc	mg/dm^3	Measurement Technique (MT) 3057-2008	Not define	No more than 5	0.094	0.013	0.033	0.028
Cadmium	mg/dm^3	Measurement Technique (MT) 3057-2008	Not define	No more than 0.001	–	–	–	–
Lead	mg/dm^3	Measurement Technique (MT) 3057-2008	Not define	No more than 0.03	–	–	–	–
Aluminium	mg/dm^3	GOST 18165-2014, p. 6	Not define	No more than 0.5	–	–	–	–
Cooper	mg/dm^3	Measurement Technique (MT) 3057-2008	Not define	No more than 1	–	–	–	–
Barium	mg/dm^3	GOST 31870-2012	Not define	No more than 0.1	0.041	0.021	0.039	0.091
Total coliforms	The number of bacteria in 100 cm^3	MC RB No. 11-10-1-2002	Absence	Absence	Overgrowth	Overgrowth	Overgrowth	Overgrowth
Thermotolerant coliform bacteria	The number of bacteria in 100 cm^3	MC RB No. 11-10-1-2002	Absence	Absence	Overgrowth	Overgrowth	Overgrowth	Overgrowth
Total bacterial count	Number CFU/cm^3	MC RB No. 11-10-1-2002	No more than 100	No more than 50	Solid growth	Solid growth	Solid growth	Solid growth

The initial sample of water from the lake contains a large number of microorganisms, especially algae. This came through organoleptic indexes and because of the lack of nitrates and nitrites in the water composition. Moreover, the increased microbial number was detected regarding all the samples. These results were obtained because of a significant amount of microorganisms contained in the lake water and the mineral fraction's inability to capture particles of such a small size.

Presence of various ions such as Mg^{2+}, K^+, Ca^{2+}, Na^+, Mn^{2+}, Ba^{2+} is essential for the normal functioning of human body and other living organisms.

The initial magnesium content in Sample No. 1 was 14.13 mg/dm^3, in Sample No. 2 it was 73.57 mg/dm^3, in Sample No. 3 it was 50.96 mg/dm^3, in Sample No. 4 it was 31.34 mg/dm^3. You can see that there was a sharp acceleration of the magnesium amount in Sample No. 2 caused by the primary wetting of the loading and absorption of excess mineral dust. In other samples, the magnesium content has decreased due to washing out of residual dust. A person needs 0.4 mg of magnesium per day to perform normal vital processes in muscle tissue [1]. Part of the needed amount comes with food, and the rest should come with water.

Potassium is also one of the important elements. In Sample No. 1 its content was 3.61 mg/dm^3, in Sample No. 2 it amounted to 1,355.15 mg/dm^3, in Sample No. 3 it was 547.11 mg/dm^3, and in Sample No. 4 it was 167.1 mg/dm^3. The following content fluctuation was observed during the experiment. Potassium content increase is a result of the water contact with banana peel. Then it decreased because of primary washout of potassium ions from intercellular spaces. Subsequent water saturation with potassium is caused by its release from the cells through a semipermeable membrane. The daily potassium requirement for humans is 1 mmol/kg [1].

The concentration of calcium in the pure lake water was 51.98 mg/dm^3, in Sample No. 2 it was 0.46 mg/dm^3, in Sample No. 3 it amounted to 10.22 mg/dm^3, and in Sample No. 4 it was 20.89 mg/dm^3. Calcium, along with other alkaline earth metals, is responsible for water hardness. The content of calcium should be controlled within the range 25–130 mg/dm^3 [15]. Initially, calcium was almost completely absorbed by the sorbents' pores. And later (after water passing) the calcium content increased.

There was a high concentration of bicarbonate in Samples Nos. 2–4. A large amount of metal ions results from their infiltration from mineral dust during the primary water passing through the additives together with calcium ions. The daily calcium requirement is 800 mg [18].

The manganese content in Sample No. 1 was 0.011 mg/dm^3, in Sample No. 2 it was 0.244 mg/dm^3, in Sample No. 3 it was 0.155 mg/dm^3, in Sample No. 4 it amounted to 0.034 mg/dm^3. In Samples Nos. 2, 3 increase in manganese content is observed because of its presence in mineral dust, which later was washed away. The daily manganese requirement is 1.8–2.6 mg [19].

Permanganate oxidation is one of the characteristics of organic pollutants. In Samples Nos. 2, 3 the content increased in comparison with the initial Sample No. 1 due to possible organic substances from banana additives, in Sample No. 4 the content was normalized.

Heavy metals, petroleum products, nitrates, nitrites, ammonia, and ammonium ions above normal are not found in the observed samples.

There were passed 50 l of water through the additives, including the first 15 l for wetting the device surface and pores of minerals. The first water came out in an hour after its filling, then the speed of water passing was 5 l/h. In total, 35 l of water were completely purified owing to the loading use. Total water volume that was taken out after purifying for testing amounted to 15 l.

D. Future Lines of Development

The developed system allows purifying natural water from primary organics such as small organisms, algae, etc. Nevertheless, the research results demonstrate that it is needed to improve the purifi ation process in order to dispose of microorganisms. Ultraviolet exposure, heat treatment, ultrasonic treatment, and gamma interaction can be employed for this purpose.

The pores of the additive minerals contain a large amount of mineral dust, as shown by the results of Sample No. 2 analysis. This dust affects the water quality, so it should not be used as drinking water. In Samples Nos. 3, 4, there was a decrease in value of the observed indexes and the water composition became closer to the optimal variant. Such water can be used for drinking after the disinfection process.

Reviewed mineral additives provided a satisfactory purification for the tested 50 l of water. When passing a larger volume of water, the water purity will be the same as in Sample No. 3. It is expected that [6, 8, 9] operational time of schungite, jadeite, quartz, gravel, flint, zeolites will be about five years; charcoal loading should be replaced according to its pollution with organics and new materials can be obtained from growing wood in enclosed systems. In subtropical zone, the best sources for charcoal materials are olive trees, quebracho, and lapacho [20]. In temperate zone, beech and birch can be used. The average output of charcoal from 1 m^3 of wood is 200 kg. Roasting and backwash of other minerals loading components will provide renewability of the purification system.

The banana fraction was used to saturate the water with potassium and to improve its taste characteristics. It is planned to create a subtropical climate within EcoCosmoHouse (ECH), where bananas will grow as food for humans and animals. However, it is worthy to consider the analogues of banana loading or alternative variants of its use in order to enable its employment for purifi ation of more than 50 l of water. One of the possible improvement alterations is to sublimate banana peel.

This experimental system is intended to review mutual action of the selected minerals and ion saturation of water during the purification process. The key direction of further research is to engage live components and estimate their influ nce on the purification process in order to improve the current device with respect to qualitative removal of microorganisms, as well as increase in organoleptic properties of the purified water. Besides, the work on the device design development will continue to provide its convenient practical application.

22.2 Use of Chlorella for Oxygen Production and Wastewater Treatment in Enclosed Ecosystems

For a long time, the space industry considered chlorella as a useful plant with a set of universal properties: requires small space, is an oxygen generator and a completely edible biomass containing almost all nutrients for the human body. Many experiments have convincingly shown that, while implementing space megaprojects, it is convenient to use chlorella as a source of oxygen and water. Recently, another very valuable ability for astronautics was discovered – the ability to clean atmosphere from harmful impurities [21].

One of such megaprojects in the near-Earth orbit, ready to be implemented in the coming decades, is the SpaceWay subprogramme developed by engineer A. Unitsky. The key element of this project is biospheric ECHs, for which chlorella can act as an “oxygen cushion” [2]. Based on the above, the objectives of this paper are the study of the possibilities of using chlorella in the generation of oxygen and wastewater treatment, as well as the development of conceptual solutions related to these processes for ECH.

Chlorella is unicellular green alga that can act as autotrophic and heterotrophic organism [22]. Special benefit can be provided by the biochemical composition of chlorella (Figure 3), which includes not only a specific set of vitamins and minerals but also has a high protein content, which determines the nutritional value of the corresponding product (the richest composition of biologically active substances) [23]. In this regard, chlorella has great economic importance. In particular, this alga can be used as a food supplementary [24, 25] feed for animal husbandry [22], and the suspension of chlorella – for soil fertilisation [26].

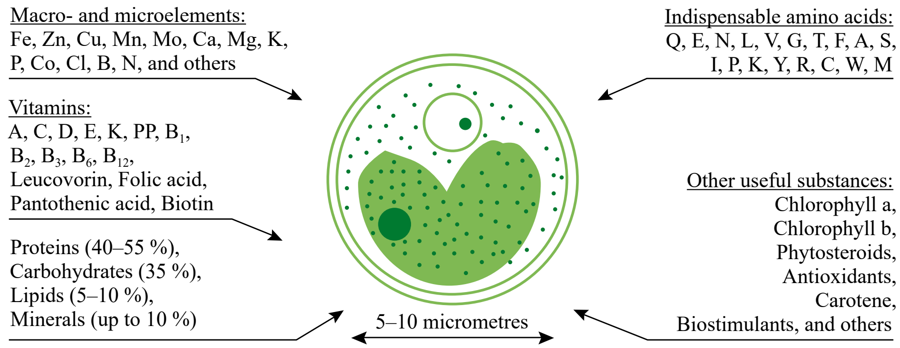

Figure 3 – Biochemical composition of chlorella

In addition, additional interest is in the research of the potential of chlorella for the production of oxygen and wastewater treatment in closed ecosystems. Up to date, there has been an experience with similar use of chlorella in the framework of BIOS-3 project [27, 28].

The general scheme of waste management in ECH is a dual system (Figure 4) for processing of solid and liquid fractions.

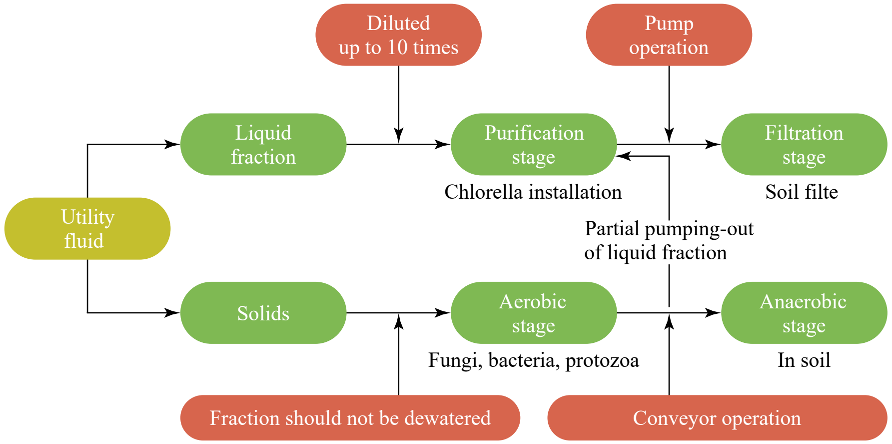

Figure 4 – Waste management concept scheme

It is noteworthy that a signifi ant part of the generated waste is in the liquid state (Figure 5). Under normal conditions, the average water consumption per day per person is about 182 l (data was obtained experimentally in urban environments), most of which is transformed into waste. These wastes can be recycled using advanced biotechnologies.

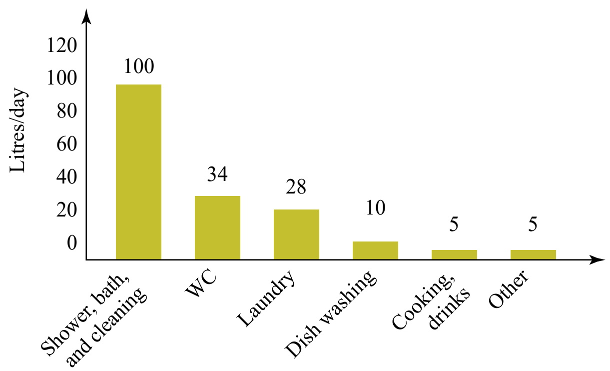

Figure 5 – Average amount of liquid waste generation per person per day

The liquid fraction of waste can be recycled using chlorella plants. For these purposes, generated liquid fraction of sewage goes into the chlorella cultivation tank. The volume of wastewater processed by the system is sufficien for photosynthesis

(according to our estimates, one part of the liquid waste should correlate to 10 parts of chlorella suspension). At the stage of wastewater formation, it is proposed to use only environmentally friendly and natural hygiene products and household chemicals to reduce the chemical load within ECH.

When cultivating chlorella in a wastewater-based nutrient medium, required minerals for nutrition should be added during the household activities of the people living in ECH, considering that the wastewater is forwarded to the common collector. Also, the possibility of introducing wastewater from the economic units (animal husbandry and crop production) was considered. The quality of the collected liquid fraction should be constantly observed to monitor the toxic fraction for the chlorella. As a benchmark for testing against the nutrient medium from wastewater, various media should be selected, as was proposed by expert scientists [22]. Meanwhile, chlorella – contained system should work with a certain photoperiod in order to conduct wastewater treatment as quickly and efficientl as possible (the possibility of using autotrophic and heterotrophic types of chlorella feeding).

The next phase is filtration of the suspension through a sand filter and transfer of formed aqueous medium to the swampy section of the fresh lake (natural filtratio fie d), where plants capable of performing biological water purifica ion (cane, typha, duckweed, nutsedge, reed, etc.) should be used. In addition, zoological objects should be included in the process as much as possible. In particular, at one of the stages, bivalve mollusks can be used during the process. They serve as water environment chemical state indicators: when the chemical composition of the treated water is unfavourable, the clams of the mollusks are closed, and a change in the biological rhythms is noted. In addition to biological indicators, it is required to conduct a speed test of the chemical composition of the water directly at the outlet of the chlorella cultivator. In case the water quality at the outlet of the installation does not correspond to the declared parameters, the term of wastewater treatment should be extended.

Closed-type photobioreactor (Figure 6) is proposed for conversion of solid fraction into liquid in order to achieve the fastest waste process. Photobioreactor is a closed tube or another enclosed tank of a transparent material capable of transmitting light, which is necessary for photosynthesis. After the process of mixing with the wastewater, the mixture can already be supplied to chlorella-contained system.

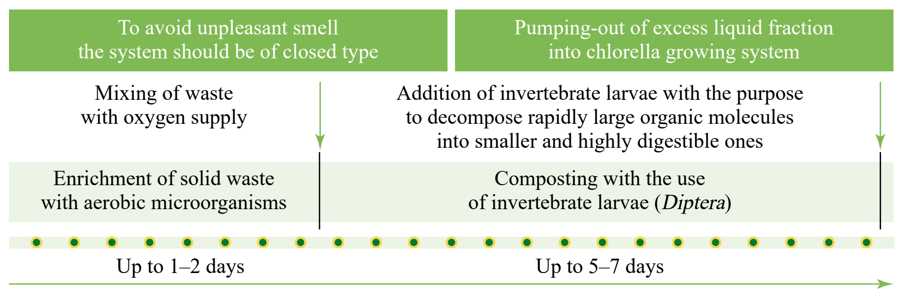

Figure 6 – Element of a biological reactor for processing solid waste fraction

Photobioreactors of the closed and open types are proposed to be used in chlorella cultivation systems. Such solutions are widely used in human economic activity (the same photobioreactors will be used at all stages of waste processing).

An open-type cultivator can be seen as an aquarium that has a significant open surface. Such a system has a great advantage in terms of oxygen evacuation from the system's surface. At the same time, with open cultivation, a greater addition of chlorella uterine solution to the system is required (with a frequency of 3–5 days), since gradually an increasing number of different types of invertebrate animals that can enter the system along with the waste will be observed in the system. In systems of the enclosed type (glass and plastic pipes of different diameters, transparent cubes, etc.), this problem is practically excluded. In order to optimise the work, it is proposed to use a combined system, which will improve the quality of cleaning and increase the volume of oxygen produced in ECH. Combined system includes 80 % of the installation volume occupied with a closed photobioreactor and about 20 % as an open one.

An open-type photobioreactor for chlorella cultivation is a chlorella suspension tank equipped with a compressor that constantly supplies air into the tank and simultaneously performs non-mechanical mixing of suspension (the general scheme is shown in Figure 7).

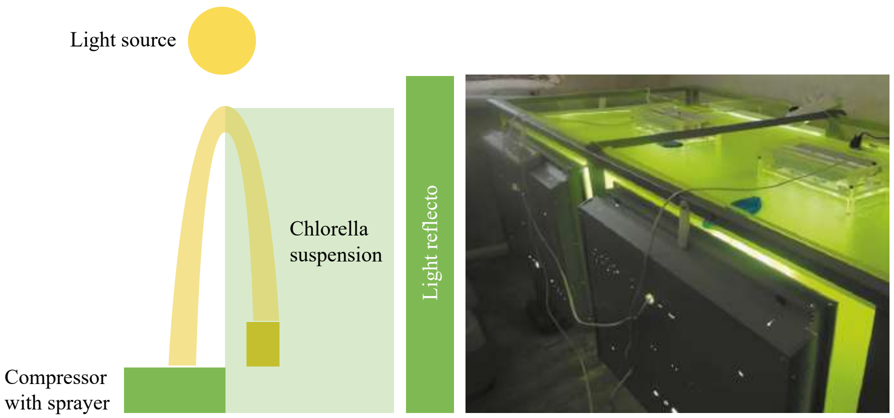

Figure 7 – Scheme and appearance of open-type photobioreactor for chlorella cultivation

At the same time, the use of closed-type photobioreactors (Figure 8) requires the development of a circulation system to perform required gas exchange processes to develop chlorella suspension. In the case of using a tube-type photobioreactor, it is necessary to provide an oxygen desorber and a system for supplying carbon dioxide or air with its high content. To decrease complexity of the installed equipment, developed installation includes open-type and closed-type photobioreactors.

The process of oxygen production is also important. According to the results of the experiments with the Siren photobioreactor, it was found that for a person's life in an enclosed ecosystem, 25 l of chlorella suspension are sufficient,

Figure 8 – Photobioreactor for closed-type chlorella cultivation

which release 429 g of oxygen per day (under normal conditions, the density of oxygen is 1.43 g/l [29]), i.e., about 300 l of O_2 [30]. The small dimensions of the oxygen maintenance equipment make it possible to redirect the excess of oxygen to a whole range of other biological and physical processes. Furthermore, it is proposed to use oxygen desorber to create backup storage, as well as to control the concentration thereof in the air.

Considering the given facts, the appropriate installation size was calculated to support living conditions for a thousand people within ECH conditions. The capacity of photobioreactor in ECH should be at least 25,000 l of chlorella suspension. It will release about 429 kg of oxygen per day with the necessary 906 kg/day of oxygen for a thousand people (with moderate loads, on person needs on average 0.906 kg/day of oxygen [31]). However, taking into account variety of the oxygen consumption processes within ECH (composting, soil formation), as well as breathing of amphibians and aquatic animals, fish, birds, etc., it is necessary to use plants for growing chlorella with a capacity of about 50,000 l (provided photosynthesizing meadow and forest plants will additionally produce oxygen in ECH).

Installation of the photobioreactors can be done at one of the ECH's walls, closer to the agricultural block (crop raising and cattle breeding). The optimal production of oxygen by chlorella is possible with a maximum duration of daylight of about 20 hours (night – four hours).

The resulting suspension of chlorella can be used as a soil fertiliser and feed additive in animal husbandry. It is intended to cultivate chlorella separately on a special nutrient medium in order to obtain additives to human food. Finally, the use of chlorella allows solving a number of issues related to the viability of the closed ecosystem at ECH, in particular, the task of gas exchange and wastewater treatment.

22.3 Specially Purposed Plants and Their Use in EcoCosmoHouse

Currently, selection of plants and methods of their use in various fields are very relevant for EcoCosmoHouse as a confin d biosphere, for example, to replace traditional household chemicals, cosmetics, antimicrobial agents, etc. Special purpose plants can be used as an alternative material – soap, dyeing, insect-eating, phytoncide-containing, etc. The term “special purpose plants” means the most suitable types of plants with useful properties [2].

Let us consider in more detail the main classes of plants taking into account the conditions of their growth in ECH. Historically, the first detergent was water. However, when water did not help, people used saltpeter, ash, sawdust, egg yolks, etc. In many countries, “soap” plants were used for washing the body and clothes due to special substances contained in them – saponins. (from Latin *sapo* – soap) [32].

Saponins are usually found in plants in dissolved form in the cell fluid of almost all organs. The number of saponins varies widely. Table 2 lists the plants that have saponins [33].

One of the most common plants is *Saponária officinális* (“soap grass”, “red soap root”, “dog soap”). When rubbing the roots (especially pre-dried and crushed) with hot water, there appears a lush foam that does not subside for a long time. The content of saponin in *Saponária officinális* is up to 32 %.

In addition to *Saponária officinális*, soap nuts are widely known – the fruits of a soap tree (up to 40 % of saponins) [34]. Aqueous solutions of soap nuts have a number of useful properties, such as antibacterial, anti-infl mmatory, emollient, nutrient, moisturizing, and whitening.

Table 2 – Plants containing saponins

Plant	Family	Plant material
Aralia mandshúrica	*Araliaceae*	Roots
Astragálus dasyánthus	*Fabaceae*	Shoot system
Dioscoréa caucásica	*Dioscoreaceae*	Root system
Dioscoréa nippónica	*Dioscoreaceae*	Root system
Panax ginseng	*Araliaceae*	Roots
Oplopánax elátus	*Araliaceae*	Root system
Rhapónticum carthamoídes	*Asteráceae*	Root system
Glycyrrhiza glábra	*Fabaceae*	Roots
Glycyrrhiza uralensis	*Fabaceae*	Roots
Tríbulus terréstris	*Zygophylláceae*	Shoot system
Saponária officinális	*Caryophylláceae*	Roots
Adōnis vernālis	*Ranunculaceae*	Shoot system
Siléne vulgáris	*Caryophylláceae*	Shoot system

Under ECH conditions, it is advisable to grow soap trees, since their fruits can be used for washing in their pure form (replacing detergents and household chemicals) or in the form of a powder based on soap nuts. Soap trees grow well on loamy soil and do not require special care.

Another useful plant species suitable for cultivation in ECH is dyeing plants containing dyes (pigments) in their organs and tissues (leaves, roots, stems, fruits, flo -ers, seeds) used for the production of dyes. Dyeing plants were among the first that people began to use for dyeing fabrics: processed in this way, they did not fade in the sun, did not lose colour, were safe for human health [35].

Currently, due to the expansion of the production of synthetic aniline dyes, vegetable dyes are used only in the traditional and silk industries. Turmeric, henna, madder, marigold, barberry, pomegranate, etc. are among the most famous plants of this class. Under ECH conditions, dyeing plants can be used to dye not only textiles, paper, and wood but also oil, cheese, rice, bakery products.

In our opinion, interesting in terms of use in ECH are insectivorous plants that can catch and digest insects and small animals. There are about 500 species of such plants. They mainly grow in places with high humidity; they compensate nitrogen deficienc with caught and digested victims. The most common species are the Venus flytrap, sundew, butterwort, and sarracenia. These plants are suitable for breeding under ECH conditions and in addition to catching insects can perform a decorative function [36].

Some of the most important plants with a wide application value are plants rich in phytoncides, substances of plant origin that have the property to slow down the growth of microorganisms and, in some cases, to kill them. Phytoncides include certain essential oils. Phytoncides provide the natural immunity of plants, serve as growth and development regulators, participate in the processes of respiration and thermoregulation. The main representatives of the class of plants containing the maximum amount of phytoncides are pine, silver-fi , spruce, oak, poplar, onion, garlic, horseradish, mustard, etc. These plants, which also affect the composition of the atmosphere, are suitable for growing under ECH conditions. Recovery of phytoncides from raw materials can occur, for example, by extraction [37].

Among special purpose plants, phytofilters occupy an important place. They are capable of absorbing harmful substances from the air, dust, and electromagnetic radiation. Currently, there is a whole direction – phytodesign, which takes into account the positive influence of plants on humans. The most famous flower – aloe – is able to purify the air of formaldehyde. *Hedera helix* absorbs up to 90 % of benzol. *Maranta leuconeura* absorbs ammonia and helps to humidify the air. These properties are very important in ECH conditions [38].

For ECH, sweetener plants are of interest. The plants of this group – stevia, Jerusalem artichoke, licorice, etc. [39] – contain natural sugars that are more beneficial and less caloric than sugar from sugar beets.

Plants can be effectively used as a substitute for many products of the chemical industry. The production of valuable products from vegetable raw materials does not require complex hardware design and does not pollute ECH. Table 3 shows the calculations on necessary costs and ECH areas for each of the plant species.

Table 3 – Calculation of the number of special purpose plants to provide ECH with required products of natural origin

Description of product	Consumption rate of plant products per month per person, kg	Quantity of products per month to feed 100 people, kg	Quantity of products obtained from one plant per month, kg	Number of plants, pieces	Occupied area, m^2
1. Plants – detergents (soap nuts *Sapindus Mukorossi, Sapindus Trifoliatus*)	1	100	5	20	200
2. Dyeing plants (turmeric, henna, madder, marigold, barberry, pomegranate, etc.)	0.05	5	0.1	50	100
3. Insectivorous plants	Not consumed	Not consumed	Not consumed	50	5
4. Plants rich in phytoncides	Not consumed	Not consumed	1	100	200
5. Phyto-filter plant	Not consumed	Not consumed	Not consumed	100	10
6. Sweetener plants (in terms of stevia)	0.6	60	0.025	2,400	500

Based on the above, it is of interest that the authors studied several representatives of special-purpose plants, assessed and visualised their useful properties in the framework of the ECH project.

Objects of study: samples of plant material (pine and spruce needles), soap nuts *S. Mukorossi*, *S. Trifoliatus*.

Experimental Part

1. For extraction of essential oils, samples of pine and spruce needles, pre-fine cut in a knife grinder up to a length of 3–6 mm, were mixed with ethyl alcohol and water in mass ratios in terms of dry matter 3 : 1; 2 : 1; 1 : 1; 1 : 2; 1 : 3; 1 : 4; 1 : 5 and left in a closed container for 7–10 days to obtain a concentrated infusion.
2. For production of detergents, soap nuts were soaked in water for a day in the ratio of 3 : 4 by weight. The resulting mixture was processed in two different ways, depending on the desired final product

- to obtain a detergent powder, the mixture created in step 2 was ground without addition of water. At the same time, the formed thick foam was dried in a layer of 1–3 cm at 40 °C temperature for 24 hours and ground until a powder with a particle size of 0–2 mm appeared;
- to obtain liquid soap, two parts of water were added to one part of a mixture of soap nuts and water. Then the mixture was ground in a knife grinder at minimum speed for a long time. The resulting dark brown suspension was filtered, the filtrate was evaporated to a viscous solution containing 15–20 % of saponins by weight.

Results

Coniferous essential oils are natural phytoncides with the strongest properties. In the course of the work, the optimal way of extracting coniferous oils from natural raw materials – spruce and pine needles – by distillation was chosen. Figure 9 shows coniferous extracts obtained with different ratios of raw materials to alcohol. It is defined that the ratio of raw materials to alcohol should be 3 : 1 to obtain the maximum yield of essential oil, however, at a ratio of 2 : 1 and 3 : 1, the product yield is almost identical. The degree of extraction is significantly less in the aquatic environment than in alcohol. Infusion time is at least 10 days. The degree of raw material grinding also has a signifi ant effec (optimally – the maximum possible).

Figure 9 – Alcohol coniferous extracts of phytoncides

Alcohol Infusion

The most concentrated sample was created at a ratio of needles to ethyl alcohol 3 : 1, however, difficultie arose in recovering the extract by pressing. The ratio of needles to alcohol 2 : 1 is preferable from the point of view of technological effe - tiveness of obtaining an infusion during extraction with ethyl alcohol. In this case, a concentrated extract is formed, which can be separated from vegetable raw materials without serious losses. It was easiest to recover extract at a ratio of needles to ethyl alcohol 1 : 5, but at the same time, it has a low concentration of active substances.

The obtained essential oils are proposed to be used for cosmetic purposes by applying to the skin (by pipette) or in the form of ice coniferous cubes.

As a result of grinding soap nuts (depending on the degree and method of grinding), two types of products were made suitable for use – liquid soap and powder obtained by drying the foam (Figure 10).

a) b) c)

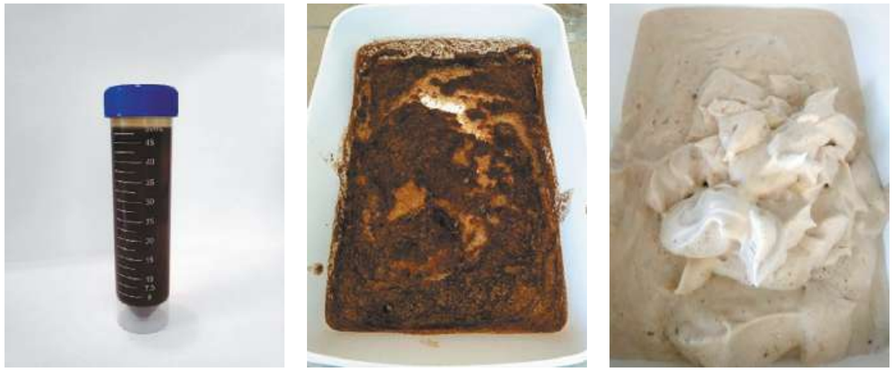

Figure 10 – Products derived from soap nuts: a – detergent (liquid soap); b – powder; c – emulsion

Liquid soap can be used independently as a detergent or personal hygiene product. Powder created by drying the emulsion can be formed in bars or used without further processing. Both products foam well, have a characteristic smell of soap nuts. The washing ability of these samples is quite high, which makes it possible to introduce natural flavors, dyes, and biologically active substances into these products to obtain products with the desired properties.

Thus, the research presented the results regarding the study of the main classes of special-purpose plants, which can be useful for ECH conditions by their properties. It has been established that the optimal ratio for obtaining coniferous extracts from phytoncide plants is a raw material: alcohol 2 : 1.

Extraction of phytoncides is more reasonable to do with 96 % alcohol, as this provides a higher rate and completeness of extraction. Compared to extracts with low alcohol content, the extract of phytoncides thus formed evaporates more intensively. As a source for the production of alcohol by the total of indicators (% of alcohol yield, an area occupied by plants), potatoes are best suited. From 1 kg of starch by fermentation, taking into account losses, 0.675 l of 96 % alcohol is released. The starch content in potatoes is 14–25 % for highly starchy varieties (Elizaveta, Skarb, Red Scarlet, etc.). In this case, 0.095–0.169 l of 96 % alcohol or 0.228–0.406 l of 40 % for other uses will be obtained from 1 kg of raw material. Based on experimental data, about 1.05 l of 96 % alcohol and 0.25 kg of needles are needed to produce 1 l of phytoncide extract. Accordingly, 5.9–10.5 kg of potatoes will need to be processed to obtain 1 l of phytoncide extract.

Emulsion and powder suitable for use as a substitute for traditional detergents are created from soap nuts.

22.4 Environmental Biodegradable Paper-Based Materials and Their Use in Enclosed Ecosystems

The increasing rates and volumes of production by the developing industries cause significant damage not only to the environment but also to civilization as a whole. It will lead to the degradation of the biosphere and humanity as one of the species [40]. Therefore, actual consideration is the removal of harmful productions beyond the biosphere, as well as the formation of space settlements created for the space industry servicing [2]. In the conditions of these settlements, which are enclosed ecosystems, people will manage the economy and control the production process to ensure life.

One of the options for the space settlements described above is EcoCosmoHouse [2], in which it is planned to recreate the terrestrial biosphere, create comfortable conditions for human life and activities, provide it with everything necessary to stay in a confined space for an unlimited amount of time [2, 41].

In the conditions of the isolated ecosystem of ECH, it is really important for a person to use items necessary for life and work, made of biodegradable materials, including paper-based ones. After all, these materials are widely available and do not require additional efforts for their disposal [42]. On average, on Earth, human consumption of paper-based products equals 20–30 kg per capita annually. Under ECH conditions, it seems possible to reduce the consumption of paper-based products to 10 kg per person annually. It is important to consider the possibility of usage of paper-based materials, for example, kraft paper, in unusual applications like sterilisation of reusable medical materials made of glass, ceramics, and metals. The existing use of the kraft paper is optimal since it is resistant to the high temperature and pressure conditions, as well as medical instruments, remaining in kraft paper after sterilisation, can maintain sterility for a long time.

It was decided to consider the manufacture, processing, and disposal of ecological biodegradable paper-based materials as the key option for providing residents in ECH with both kraft paper and hygiene products (toilet paper, paper towels, napkins, etc.). The transportation of these products from Earth is impractical because they are often disposable in use and take up rather large volumes. It is relevant to manufacture these products under ECH conditions and in the sufficien quantity that a person needs.

The purpose of this research is to propose a process for the manufacture of sanitary, hygienic, and medical products from cellulose-containing plant materials, such as, for example, toilet paper, napkins, paper towels, kraft paper, and much more, to ensure the safety and environmental friendliness of an enclosed biosystem.

A. Formulation of the Problem

Currently, many products contain polymeric and other chemical components that cannot be easily recycled, or their possible recycling and disposal processes will be impractical under ECH conditions since they will pollute the biosystem [42]. To avoid this problem, it is proposed to make these products from cellulose-containing materials, such as waste paper of various types and qualities, as well as from the waste from the cultivation of various types of plants [42]. The last one may include rice husks [43, 44], straw, cotton [45], mud, algae, stems, leaves [42, 46, 47], fallen leaves, and other organic wastes. These materials have the necessary set of performance properties: softness, fiber flexibi ity, and undemanding manufacturing process. This means that it is possible to produce both materials containing 100 % of one component of a given raw material, and materials consisting of a mixture of components, depending on the required properties of the final product. You can also make paper products, both from the production waste of these products, and materials obtained after their use and processing [42].

The advantage of these paper materials is that they are biodegradable. The environmentally friendly process of their manufacturing is characterised by the simplicity of the technological processes, ease of disposal, or recycling of the used products. The raw materials used for manufacturing are renewable, which allows them to be disposed without additional stages. Raw leftovers of the various plants are suitable for the manufacturing of the final product, including waste after growing both annual and perennial plants [42].

Paper-based products are safe and suitable for use in everyday personal life and are also completely recyclable (this process does not require additional energy consumption and can be represented as recycling of products). The products described above do not harm nature and human health [41, 42, 46].

B. Description of the Proposed Technology

The proposed technological process can be characterised as cyclic, it is possible to produce the required amount of consumed products without a large amount of warehouse stocks, which means that additional territory will not be needed to stock up finished products. Figure 11 shows a general manufacturing scheme of the items for hygiene and medical applications within ECH conditions.

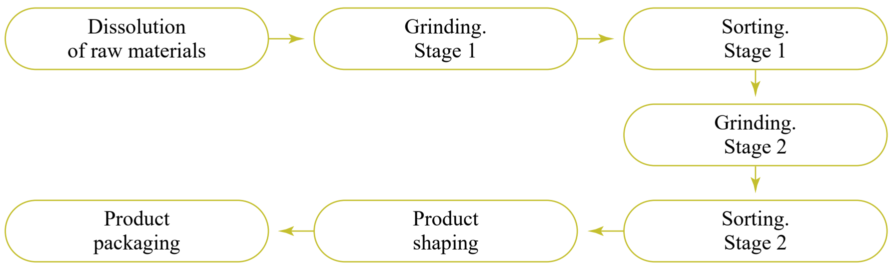

Figure 11 – Scheme of manufacturing paper-based materials

The type of feedstock depends on the product being manufactured. It is advisable to divide all types of products into two important classes: paper products for sanitary purposes (toilet paper, napkins, paper towels) and medical (kraft paper) purposes.

For the manufacture of sanitary and hygienic products, it is possible to use rice husks, straw, hemp, cotton, mud, algae, stems, leaves, fallen leaves, as well as any waste paper and other waste from the cultivation of plant materials containing cellulose.

For the manufacture of medical products, it is advisable to use mainly straw and stems left after growing plant raw materials or waste paper – kraft paper is used for its intended purpose and has lost its properties. Such a limited choice is due to the requirements for the finished product, namely, the presence of long fiber and a high content of cellulose in the raw material, the amount of which can reach up to 90 % but not less than 40 %.

The technological scheme includes several stages, as a result of which a finished product with the required quality is obtained from the feedstock: dissolution, grinding, sorting, molding, and packaging. The grinding and screening stages include two processes: coarse and fine grinding and screening

At the stage of breaking up the fibrous raw materials, the raw material is defibrate and separated into fibers [42, 46]. To obtain a suspension, water is added (mainly recycled water from the previous stages), and it also includes the additional waste components to be processed, which can be sourced from the subsequent stages of sorting.

Hot water extraction with a temperature of 60 °C using an acidified medium can be used as additional substances to activate the production of a cleaner finished product; citric acid can be used at this stage. It seems possible to carry out the extraction at the stages of dissolution, grinding, or to install a separate tank with a stirring device for the course of the corresponding processes.

Grinding is a mechanical separation process that leads to changes in the size and shape of the fi ers, as well as colloidal-chemical processes – the hydration of the fibers and their swelling (Figure 12)

At this stage, necessary manufacturing additives are added to the mixture, for example, disinfectants, dyes, and various others.

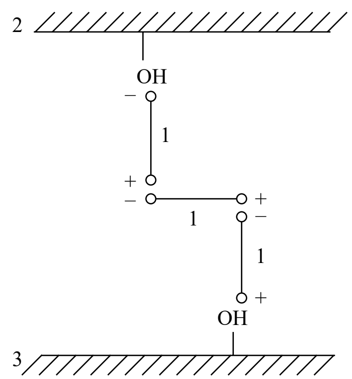

Figure 12 – Scheme of bridging interfiber bonds through water d poles:
1 – water dipoles; 2 – the first fiber; 3 – the second fi

Since paper-based products will be used as sanitary and hygienic and medical products, it is necessary to use disinfectants at the final stages of the manufacturing process. In this work, it is proposed to use well-known plants with high concentration of saponins and phytoncides [41], they also have dyes that, when in contact with the skin, will not have an adverse effect on the human body. This is important, since when using conventional chemical dyes, for example, azo dyes and aqueous dispersions of organic and inorganic pigments, allergic reactions may occur when they come into contact with the skin [42].

The use of leaves or fruits of a soap tree in the technological process is another promising solution [41]. The foam from them will create a uniform mixing of the fibers, and the paper will be obtained with a more uniform clearance, which will affect its physical and mechanical properties. Also, it is possible to use chlorella [41], which, in addition to possessing bactericidal properties, is also capable of producing oxygen. The consumption of all of the above auxiliary substances is very low (up to 50 g/ton of finish d products), and therefore their use has high potential. These substances do not affect the technological process and they can be introduced into the technological line at the stages of either breaking up or grinding.

During screening, the fi rous milled slurry is separated into a fi rous slurry for further processing and waste or large clumps of fibers, which are sent to the first or second grinding stage, respectively.

The second stage of grinding and screening is similar to the fi st.

Product shaping and packaging are the final stages that allow production and shape of the finished product and package it

Table 4 shows the need for personnel and the time required for the manufacture of paper-based products at the rate of 100 kg/h.

Table 4 shows that 500 kg of products will be manufactured in five hours of work, if an already established manufacturing process is being considered since the initial launch of the manufacturing process requires additional time and labour force.

Table 4 – Requirements of the technological process for 500 kg of paper product

Stage name	Need	
	Process time, min	Labour costs, person-hour
0. Preparation	60	1
1. Dissolution	30	1
2. Grinding. Stage 1	About 10 (controlled by the degree of grinding)	0.5
3. Sorting. Stage 1	60	1
4. Grinding. Stage 2	About 30	1
5. Sorting. Stage 2	40	1
6. Forming	60	2
7. Packing	20	0.5
Total	300 (five hours	8 (one shift)

Daily operating time will depend on the needs of ECH's residents. Considering the average annual consumption of 10 kg per person, it will be necessary to make paper products in a total amount of 10,000 kg for 1,000 people annually.

The presented technology is not time consuming, does not occupy large areas (about 100 m^2 with a capacity of 500 kg per shift, or 10 m^2 at 50 kg per shift), has the ability to run a continuous production, does not have harmful emissions, and it is also environmentally friendly.

The process of recycling the used products is the collection of the waste products, sorting and sending them to the dissolution stage.

C. Conclusions and Future Directions of Research

The proposed manufacturing process of sanitary, hygienic, and medical products from cellulose-containing plant materials, such as, for example, toilet paper, napkins, paper towels, kraft paper, and others, ensures the safety of the production process itself and its environmental friendliness. Products will be made from biodegradable raw materials and will be recycled, which will be harmless in a closed ecosystem. Under ECH conditions, people will have the opportunity to create more comfortable living conditions for themselves compared to living in an enclosed ecosystem without environmentally friendly paper-based materials, if we assume that planet Earth is also an enclosed ecosystem.

In the future, research will be carried out in the fi ld of optimising the characteristics of the equipment for the manufacture of the presented type of paper-based products.

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23

Development of Social, Political, and Legal Foundation for the Programme of Space Industrialization

23.1 Socio-Political Framework of the SpaceWay Subprogramme Implementation

In the 1970s, A. Unitsky, the engineer and author of the SpaceWay project, started substantiating the need for space industrialization. His idea implies that the environmental problems are an expected result of the technocratic civilization development, which created an industry on Earth that entered into relationship of irresolvable antagonism with the planet's biosphere. "There is only one principal way out of this situation," writes A. Unitsky. "It is necessary to provide the technosphere with an ecological niche outside the biosphere. This will ensure the preservation and development of the biosphere in accordance with the laws and trends that formed during a billion years of evolution, as well as the balanced interaction of the community of people (as biological objects) with the biosphere. There is no such ecological niche for the technosphere on the planet Earth. But there is one in the space, where there are ideal conditions for the most technological processes: weightlessness, deep vacuum, ultrahigh and cryogenic temperatures, unlimited raw materials, energy, and spatial resources, etc. Thus, we conclude that there is a need of space industrialization, if the Earth civilization continues the technological path of development in the future" [1]. This idea was a prerequisite for inventing the SpaceWay subprogramme, aimed at creating the technological basis for the large-scale exploration of the outer space by mankind. The General Planetary Vehicle (GPV) developed by A. Unitsky should become such a basis.

"The GPV is a reusable geocosmic transport system for non-rocket space exploration. Within one fl ght, the GPV will allow putting into orbit about 10 mln tons of cargo and 10 mln people, who will be involved in creation and operation of the near-Earth space industry. During one year, the GPV will be able to go into space 100 times. Modern world rocket and space industry, in which trillions of dollars have already been invested, will need about a million years to repeat the same which the GPV could make within one year. At the same time, the cost of delivering each ton of payload to the orbit will be ten thousand times lower than that of the modern launch vehicles" [1].

The General Planetary Vehicle provides an opportunity to remove harmful industries from the biosphere. Thus, the mankind will be able to secure necessary conditions for improving the ecological, economic and social environment in the long-term perspectives, as the main cause of environmental pollution – the industry – will be placed outside of the biosphere. The GPV will from a new sizable production niche, initiate innovative scientifi and technical activities and enable access to new raw materials and spatial resources. Implementation of the SpaceWay subprogramme will require collaborative actions at the international level. In this regard, along with the scientific, technical and economic aspects, a question of socio-political framework arises, which should unite the subjects of the subprogramme.

In modern dictionaries and encyclopedias, the concept of "community" is synonymous with the concept of "society" and has the following meanings:

- a number of people united by historically determined social forms of relationship and activity;
- a circle of people united by common position, origin, interests;
- a voluntary, permanent association of people for any purpose;
- organisation, union of people setting common tasks for themselves.

The concept of "politics" (in Greek, *politika* is the art of governing the state) is interpreted as the activity of state authorities and public administration expressing the socio-economic nature of the given society, and the activities of classes, parties, groups, determined by their interests and goals [2].

Therefore, the socio-political basis may be regarded as the central element of the system of values, which acts as a regulator for the activities of the government bodies and associations of people represented thereby, pursuing any common goals. Consequently, the search for the socio-political basis for implementation of the SpaceWay subprogramme should proceed from its goals, the main one of which today is, undoubtedly, the preservation and improvement of the ecological situation on the planet. This priority is in direct correlation with the priorities identified by the United Nations as the Sustainable Development Goals, adopted by 193 UN member states on September 25, 2015.

According to the UN statement, "The Sustainable Development Goals are a call for action by all countries – poor, rich and middle-income – to promote prosperity

while protecting the planet. They recognize that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities, while tackling climate change and environmental protection" [3].

The UN documents define 17 global goals

1. End poverty in all its forms everywhere.
2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
3. Ensure healthy lives and promote well-being for all at all ages.
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Achieve gender equality and empower all women and girls.
6. Ensure availability and sustainable management of water and sanitation for all.
7. Ensure access to affordable, reliable, sustainable, and modern ene gy for all.
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
10. Reduce inequality within and among countries.
11. Make cities and human settlements inclusive, safe, resilient, and sustainable.
12. Ensure sustainable consumption and production patterns.
13. Take urgent action to combat climate change and its impacts.
14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels.
17. Strengthen the means of implementation and revitalize the global partnership for sustainable development [3, 4].

Implementation of the SpaceWay subprogramme may be a decisive factor in achieving all of these goals. It involves creation of many new jobs, including their creation in a number of the under-developed countries [5] along the equator line, where the GPV launch overpass will be built and combined with the Equatorial Linear City.

The subprogramme will provide access to the new low-cost energy sources, create conditions for economic growth, form the foundation for creation of inclusive infrastructure. The culture of consumption and production will shift to the higher quality level, as negative impact thereof on the environment should gradually be reduced to minimum. The ecological potential of the project is enormous. The vast majority of current ecological problems can be addressed, including environmental pollution, climate change, preservation of forests, oceans and biological diversity, desertification and land degradation. Thus, there are no doubts in the global potential of the SpaceWay subprogramme and its compliance with the priorities of the international development, as recorded in the UN documents. Therefore, the UN may be considered as one of the components of the socio-political foundation of the subprogramme implementation process at the initial stages. Furthermore, it may also act as an organisational tool for a number of important functions in the context of the subprogramme.

As it was already mentioned, the GPV launch overpass should be built along the equator line, passing through the territories of several countries. However, the biggest part of it will be laid through the oceans, which will require a large number of approvals at the international level. It may be necessary to introduce amendments or additions to the international regulatory documents: for example, the UN Convention on the Law of the Sea or the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. To manage those changes, it seems necessary to create a non-profi organisation to represent the SpaceWay project at the UN. Later on, it might enter the UN organisational structure or might act independently as a lobbyist, providing the necessary interaction between other structural units within the UN and the member states. Such UN member can also be an intermediary in the context of cooperation with the scientific institutions, industrial and commercial companies involved in implementation of the SpaceWay project.

The public-private partnership seems the most likely form of funding and construction works for the SpaceWay subprogramme as of today. This mechanism was previously successfully used in a number of large international infrastructure and scientific projects, for example, Eurotunnel and the International Space Station (ISS). Nowadays, the ISS is the most expensive international scientific project. Since its start in 1998, more than 150 bln USD has been spent on assembly and maintenance thereof. Hundreds of companies took part in this project, including state structures of the USA, Russia, Canada, Japan, Italy, member states of the European Space Agency and Brazil [6]. It is obvious that the number of participants in the SpaceWay subprogramme will be no less, with the subprogramme costs, according to preliminary estimates, reaching about 2.5 tln USD. However, taking into account the fact that already within the first year of the GPV operation the economic effect from the subprogramme implementation may amount to 1,000 tln USD [1] and it will increase in the future, the attraction of the international community to participate in the subprogramme in the foreseeable future is already an achievable task, in case of systematic development of its scientific, technical, economic, sociopolitical, and other components. Since the sustainable development goals proclaimed by the UN coincide with the SpaceWay goals, and because the UN has a certain political influence at the international level, it is reasonable to consider the United Nations as one of the key stakeholders in the development of the socio-political foundation for implementation of the SpaceWay subprogramme.

23.2 Principles and Forms of International Cooperation in Implementation of the SpaceWay Subprogramme

The SpaceWay subprogramme involves construction of Unitsky's General Planetary Vehicle. This subprogramme has, undoubtedly, a worldwide scope [1, 7]. Its implementation implies direct and indirect participation of a large number of subjects of the international law. Such participation generates complex multi-level relationships between the subjects, which follow specific rules. These rules are expressed in certain forms. This research addresses the following issues:

- principles of the international law as the most common fundamental norms (rules), in compliance with which the subjects of international relations act, the possibility of their application to the relations arising between the participants of the SpaceWay project, and the possible influence of the SpaceWay subprogramme on the specified principles
- existing forms of the international cooperation as the foundation for building relationships between the participants of the subprogramme, the compliance of such forms with the needs of the project and their applicability at different stages of the GPV life cycle.

The doctrine of the international law identifies 10 universal principles [8], but in this paper we will focus only on six of them, which can affect implementation of the SpaceWay project or which can be influenced by implementation or operation of the project.

A. The Principle of Non-Use of Force and Threat of Force

According to Cl. 4 Art. 2 of the UN Charter "All Members shall refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any state, or in any other manner inconsistent with the Purposes of the United Nations" [9].

As for implementation of the SpaceWay subprogramme, the principle of non-use of force and threat of force will be realised as follows. The implementation of such a large-scale project seems possible only with the participation of the majority, if not all, nations of the planet. The participation of such a large number of sovereign subjects of the international law is possible only in case of their legal equality and absence of coercion in any form.

On the other hand, involvement of a large number of states in implementation of the planetary scale project necessary for the entire humanity will contribute to their consolidation, dispute settlement or at least smoothing of the existing conflicts and establishment of the power balance. Thus, common and globally significant goal will act as a powerful uniting factor in development of the international relations.

B. The Principle of Peaceful Settlement of International Disputes

According to Cl. 3 Art. 2 of the UN Charter "All Members shall settle their international disputes by peaceful means in such a manner that international peace and security, and justice, are not endangered" [9].

This principle of the international law has a huge impact on the process of implementing the SpaceWay project. The project combines a large number of different subjects with complex relationships. It will obviously rise a significant number of international disputes and reciprocal claims of participants. However, it should be noted, that in this situation the settlement of such disputes for the above reasons is possible only by peaceful means, without the use or threats of use of force.

Moreover, the SpaceWay project is capable to reinforce the principle of settling international disputes by peaceful means. As noted above, the pursuit of a common and globally significant goal can unite different subjects of the international law, which undoubtedly will direct settlements of all international disputes to a peaceful course. After the completion of the project, the number of international conflicts will significantly decrease, because of the two possible processes. Firstly, all efforts of the humankind will focus in a different direction: the non-rocket exploration of space and restoration of the Earth's biosphere. Secondly, many problems (territorial, resource, financial) will remain in the past since the moment of the beginning of the wide space exploration.

C. The Principle of Non-Intervention

The international law, by its nature, does not regulate the issues within the internal competence of the states. According to the legal references, the intervention is understood as "any measures by means of which the states or international organisations try to prevent the subject of the international law from settling its internal aff irs" [8].

Each state has the right to determine its own political, fi ancial, economic, social, and cultural system independently without any intervention.

At first glance, it may seem that the above principle is not related to implementation of the SpaceWay project, since it manages only the internal affairs of each state individually, but a detailed review can reveal such direct connection. Thus, each state will independently decide on its participation in the project, and since we are talking about absence of coercion and threats to build productive cooperation, such decision cannot be imposed from the outside and should be made without interfering with internal decision making mechanisms in each individual state or organisation. Each subject of the international law should independently see the need for everyone to participate in construction of the GPV as the only possible way to preserve the biosphere.

D. The Principle of Countries' Duty to Cooperate

Guided by the UN Charter, the states are obliged "to achieve international co-operation in solving international problems of an economic, social, cultural, or humanitarian character", as well as "to maintain international peace and security, and to that end: to take effective collective measures" [9]

The principle of cooperation is the basic principle of the international law, which is recognized by an absolute majority of scientists [10]. The connection of this principle with the SpaceWay project is obvious. On one hand, as construction and commissioning of the GPV solve majority of today's human problems, in accordance with the UN Charter, the states are obliged to cooperate in the works, related to the project. It will happen, once the SpaceWay project is recognized by the international community as the means of solving such problems. On the other hand, implementation of such a large-scale project is impossible without cooperation of many states.

E. The Principle of Sovereign Equality

Cl. 1 Art. 2 of the UN Charter provides that "the Organization is based on the principle of the sovereign equality of all its Members" [4]. The principle of sovereign equality implies that every state is obliged to respect the sovereignty of other states, i.e., their right to exercise legislative, executive, and judicial power on its territory without anyone's intervention and to determine independently its domestic and foreign policies.

In fact, the states differ in their development levels of economic, social, political, and other areas. To ensure proper functioning of the current system of international relations, it is necessary to have fundamentally the same rights and duties for diffe - ence subjects of the law: this is the main purpose of the principle of sovereign equality of the states.

The influence of this principle on the SpaceWay project can be characterised as follows. The most likely form of international cooperation in implementation of the SpaceWay subprogramme is an international treaty, as presented below. Furthermore, the nature of the contract itself involves participation of equal subjects, which assume certain obligations by expressing their free will.

In addition, the SpaceWay project will strengthen the principle of the sovereign equality of states, since each entity involved in the project will receive certain levers of influence, which could become the means of achieving not only formal, but also actual equality in the international relations.

F. The Principle of Faithful Fulfillment of Obligations Under International Law

The principle under consideration is determined in Cl. 2 Art. 2 of the UN Charter stating that "all Members, in order to ensure to all of them the rights and benefits resulting from membership, shall fulfill in good faith the obligations assumed by them in accordance with the present Charter" [9]. This principle is also one of the fundamental international legal customs of *pacta sunt servanda* ("treaties must be kept").

Considering this principle in the context of the SpaceWay project, the following should be taken into account in details. Construction and commissioning of the GPV is possible only with the participation of a large number of equal subjects

of the international law, whose actions, rights, and obligations are most likely to be governed by an international treaty. Therefore, the principle of faithful fulfi lment of the obligations is fundamental for the project. At the same time, the reciprocal situation can be considered: implementation of the SpaceWay project will strengthen this principle, since, being a project aimed at saving the humankind, the early completion of the GPV construction will become a significant incentive for the parties to fulfill their obligations in good faith

In legal references, the following notion for the form of cooperation exists: "Under cooperation forms we understand the framework within which the cooperation between the states takes place" [11]. However, for the purpose of this research, we use a broader definition. The international legal form of states cooperation is a joint bilateral or multilateral activity of the states carried out based on international agreements in political, economic, scientific, technical, legal, and other spheres aimed at maintaining the international peace and security and promoting the economic stability and progress [12].

There are two main forms of international cooperation emphasized in the reference literature: signing process of the international treaties and participation in the international organisations [8]. Let us consider them in relation to the implementation of the SpaceWay subprogramme. Based on the analysed approaches, the most likely form of international cooperation in implementation of the SpaceWay project, at least at the initial stage, is the conclusion of an international treaty.

An international treaty is a clearly expressed legal act concluded between two or more legal entities, which regulates relations between the parties by indicating their rights and obligations in various spheres [8]. The treaties may moderate and manage creation of the joint working groups, exchange of specialists, use of the joint educational programmes, etc. An international treaty may create a new international institutional structure (an association, organisation). The treaty may cover a particular framework, enabling the possibility of further cooperation through conclusion of additional agreements [12].

As it can be seen from the above conditions of an international treaty, scope of its application is so diverse that it will provide a platform to foresee all possible options for the parties to implement the SpaceWay project.

Cooperation within the framework of multilateral international treaties is viewed as the most effective way to implement such a large-scale space project with involvement of many states. This is due to the fact that within the framework of this form of cooperation, the interaction of the states is limited only by the norms of the international law and the will of the interested states to cooperate. The participants are not bound by the obligatory formalized procedures and by the need to receive the support of all states.

In a similar way, a high degree of adaptability of cooperation can be achieved. Afterwards, the interaction of the states can be processed promptly, bypassing the procedural constraints of certain institutional structures. The states conclude only such international legal acts that are necessary for performance of the current tasks, at the same time, retaining the possibility of their prompt revision or amendment.

The second form of international cooperation under consideration is participation in the international organisations. Cooperation may take place within the framework of the world universal international organisations. Cooperation may also be realised within the framework of the regional organisations.

With regard to the sphere under consideration, it can be stated, that participation in the international organisations is possible on a higher level of development of the SpaceWay project, which will be possible when many subjects of the international law will be interested in development of the subprogramme.

The following assumption seems reasonable, that due to the location of the GPV, a regional organisation can be created. Such structure will unite the countries on which territory the GPV will be located.

Given all the advantages of such a form of cooperation as the international treaty, it should be noted that participation in the international organisation is still more binding for the subject of the international law. Therefore, at a certain stage of the SpaceWay project life cycle, the creation of a regional and/or global international organisation will become a reasonable necessity.

The performed analysis allows us to conclude that the relationship between the subjects of the international law within the scope of their participation in the SpaceWay subprogramme fully fits into the framework established by the existing principles of the international law. At the same time, it can be confidently stated, that implementation of the SpaceWay project will contribute to the strength and strict observance of these principles by all participants of the international relations.

The forms of international cooperation considered in this research correspond to all the essential conditions for implementation of the SpaceWay project at each stage. In particular, the international treaty is the most appropriate form of cooperation at the GPV design and construction stages. At the stage of operation, it is necessary to create the international organisation.

However, the above does not exclude the option that within the process of participation of the subjects in implementation of the globally significant large-scale project, new principles of relationships and forms of international cooperation can be developed.

23.3 Legal Aspects of International Cooperation in Space Exploration

As demonstrated above, SpaceWay represents a large-scale international project for non-rocket space exploration using Unitsky's General Planetary Vehicle as the only way to safeguard the biosphere by moving industry off-Earth [1]. SpaceWay cannot be implemented by one or more countries, even the most highly developed ones due to its complexity and original design.

Most space activities can only be realised through international cooperation. That's why the topic considered here is so important for the SpaceWay subprogramme.

In this research, the author dwells on the contemporary status of international space cooperation by briefly reviewing its history and international law instruments elaborated throughout that period, and by identifying the aims and objectives pursued by international organisations in outer space activities. This information will provide the basis to conclude whether such universal large-scale space projects as SpaceWay can be implemented now or the status quo is to be altered.

A. Overview of Contemporary Status of International Space Cooperation

The natural need to regulate human space activities at the international level arose after the firs artific al Earth satellite was launched in 1957. However, regulation issues concerning the proposed future space activities started to be discussed as early as at the beginning of the 20th century with the emergence of space and rocket sciences.

In the 1920s–1930s, the works on the international air law issues argued about the need to regulate new relationships arising in outer space use and exploration. Space exploration has become a challenge to the humanity as a whole since almost any type of space activity affects the interests of the entire international community, and outer space cannot be divided, in a similar way to airspace, into national space, and international space [13]. For that reason, the legal framework had to be developed to protect the interests of the entire humanity in the process of space exploration. International law had to play a key role in that matter.

In the mid-20th century, space law issues were to a greater extent explored in the international air law related researches. Experts considered the core of international law, i.e., the principle of international cooperation, as a crucial prerequisite for the peaceful use of outer space in the interests of the human race. Issues of the airspace border and consequently vertical limitation of state sovereignty were also of interest. Such important issues as the military use of outer space, liability and compensation for damage, free outer space for peaceful and scientific purposes were also taken into account [14].

The arms race played a role in the development of international space law. In the weapons race context, land, water, and air were seen through a military perspective, and the beginning of space exploration for military purposes was only a matter of time.

The regulatory aspect of the international space cooperation were developing particularly intensively in the 1950s–1960s. At that time, all types of space activities were already known: intelligence, remote sensing, communications, and navigation. Launches of interplanetary probes, manned flights, creation of orbital space stations, and a reusable space transportation system had been planned [13].

On October 8, 1957, it was decided to set up a Special Committee for delimitation of air space and outer space law [14].

From the very start, international cooperation in space exploration was promoted under the UN auspices.

The UN General Assembly of December 12, 1959, by its resolution International Cooperation in the Peaceful Uses of Outer Space, established the Committee

on the Peaceful Uses of Outer Space (hereinafter the UN Outer Space Committee) [15]. Among other things, this resolution provided for international conferences to be convened in 1960 or 1961, under the UN auspices, to exchange experience in the use of outer space for peaceful purposes [15]. And on December 20, 1961, a new resolution International Cooperation in the Peaceful Uses of Outer Space was adopted. That resolution International Cooperation in the Peaceful Uses of Outer Space enshrined the two fundamental principles of international cooperation in space exploration:

- international law, including the Charter of the United Nations, applies to outer space and celestial bodies;
- outer space and celestial bodies are free for exploration and use by all States in conformity with international law and are not subject to national appropriation [16].

These principles were expanded in the UN General Assembly resolution Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, to enshrine nine principles of international cooperation in space exploration. This resolution formed the basis of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies of 1967 (hereinafter the Outer Space Treaty), reasonably considered by experts as the basic international treaty on outer space of the five existing ones. The Outer Space Treaty has become a kind of "charter" in space cooperation. However, modern views are expressed that its provisions are outdated and are no longer a fitting response to the realities [13]

Subsequently, other instruments were adopted to expand certain provisions of the Outer Space Treaty. They summarised the accumulating practice in outer space exploration and use.

In 1968, the International Conference on the Peaceful Uses of Outer Space (UNISPACE I) was held, and the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (hereinafter the Rescue Agreement) was signed [14].

In 1970–1972, the United Nations established the position of an Expert on Space Applications and created the Space Applications Programme to provide technical assistance to developing countries, in particular, to support national efforts in promoting space activities. The Convention on International Liability for Damage Caused by Space Objects (hereinafter the Space Liability Convention) was signed [14].

Over time, frequent satellite launches (successful or unsuccessful) and the lack of their registration have come to represent a threat of damage posed by unidentified space objects. Therefore, the Convention on Registration of Objects Launched into Outer Space (hereinafter the Registration Convention) was signed in 1975 [14].

The increasing interest shown by various countries in the exploration and use of the Moon resulted in signing the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (hereinafter the Moon Agreement) in 1979.

Unfortunately, no more international treaties have been elaborated by the UN Outer Space Committee since 1979.

However, space activities continued developing, with the number of its participants increasing. In this regard, to strengthen the UN Programme on Space Applications, which increased opportunities for all countries and indigenous peoples in the use of space technology, and to build capacity in space exploration, the second Conference on the Peaceful Uses and Exploration of Outer Space was held in 1982 (UNISPACE II). And then the third Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) was held in 1999 to highlight issues of protecting the global environment and managing natural resources.

The adoption of the five fundamental outer space treaties became the pivotal legal achievement in outer space exploration and use in the second half of the 20th century.

Analysis shows that regulatory instruments appeared in response to certain events or science and technology advances due to impossibility to predict in far advance the results of the outer space exploration and the use of cutting-edge scientifi and technological achievements, as well as challenges and opportunities the human race would face in a few decades.

Despite all the efforts to regulate international cooperation in space exploration, some issues have not yet been resolved. The existing universal treaties on this issue contain a significant part of dormant provisions and provisions either not fitting the current science and technology development level or not meeting the interests of those stakeholders involved in space activities. That is why the countries seek to fill in such gaps with national laws meeting only national interests, which are sometimes not conforming to the provisions of international treaties.

Considerable time input is required to encourage the international community to elaborate on a new universal international space treaty. Thus, several thousands of years have passed between the beginning of ocean exploration and the adoption of the UN Convention on the Law of the Sea.

In the 21st century, the UN Outer Space Committee shows the tendency towards elaborating guiding (non-binding) instruments on outer space exploration procedures. This, among other things, is related to the impossibility for countries to agree on the general will, which requires a common political vision concerning the issues under consideration.

B. International Space Treaties

The international space law is mainly based on the five treaties elaborated by the UN Committee on the Peaceful Uses of Outer Space:

- Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967);
- Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968);
- Convention on International Liability for Damage Caused by Space Objects (1972);

- Convention on Registration of Objects Launched into Outer Space (1975);
- Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979).

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies

The Outer Space Treaty defined the core principles of international cooperation in outer space exploration and use:

- the exploration and use of outer space shall be carried out for the benefit and in the interests of all countries;
- outer space shall be free for exploration and use by all countries without discrimination of any kind, on a basis of equality;
- outer space, including celestial bodies, shall not be subject to national appropriation by any means;
- the exploration and use of outer space shall be carried out in the interest of maintaining peace and security and in accordance international law;
- weapons of mass destruction, including nuclear ones, shall not be deployed;
- all possible assistance shall be unconditionally rendered to astronauts;
- international responsibility shall be borne for activities in outer space;
- countries on whose registry an object launched into outer space is carried shall retain national jurisdiction and control over that object launched and over any personnel thereof;
- international cooperation and mutual assistance shall be provided;
- all objects placed on celestial bodies shall be open to representatives of other countries on the basis of reciprocity.

As of January 1, 2020, 110 countries ratified and 23 countries signed the treaty [17].

Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space

Further to the Outer Space Treaty, this instrument regulates in detail the rendering of assistance to astronauts and introduces principles and procedure for investigating accidents involving astronauts.

The Rescue Agreement discloses and gives a further concrete expression of duties of the contracting parties to assist astronauts in the event of an accident, distress or other incidents governs the procedure in designated cases, and lists steps aimed at assisting the crew.

The Rescue Agreement provides that the launching State can be involved in search and rescue operations, subject to the consent of the State in whose territory the accident occurred.

It also focuses on the provisions for the launching authority's reimbursement of expenses incurred by a Contracting Party, which assisted the astronauts, and for the return of objects or any parts to the launching authorities upon request.

As of January 1, 2020, 98 states ratifi d, 23 states signed the Rescue Agreement, and three international organisations have declared their acceptance of the rights and obligations conferred thereby [17].

Convention on International Liability for Damage Caused by Space Objects

This convention explains and clarifi s the Outer Space Treaty provisions on obligations and liability for damage caused by space objects.

The Liability Convention is distinct for a set of terms and defin tions, which contributes to the uniform interpretation and avoidance of ambiguity.

The Liability Convention addresses the issues of liability to a third state; joint and several liability of two or more parties; conditions of exoneration from liability; conditions of non-application of the convention; the procedure to present a claim and determine compensation for damage; claims process; the possibility of rapid assistance to the affected state due to the la ge-scale damage caused.

As of January 1, 2020, 98 states ratifi d, 19 states signed the agreement, and four international organisations have declared their acceptance of the rights and obligations conferred thereby [17].

Convention on Registration of Objects Launched into Outer Space

One of the principal arguments for creating this Convention was the UN Outer Space Committee believing that "a mandatory system of registering objects launched into outer space would assist in their identifi ation and would contribute to the application and development of international law governing the exploration and use of outer space" [18]. The provisions of this convention stipulate that the data on space objects launched shall be entered into national registries and the UN centralised registry.

Space Object Register is located at https://www.unoosa.org/ (the official UN Outer Space Committee website). It contains data about the registration of the launched objects, national registries, an online index of the objects launched into outer space, and special registering forms for space objects and launch locations data.

As of January 1, 2020, 69 states ratified, three states signed the Registration Convention, and four international organisations have declared their acceptance of the rights and obligations conferred thereby [17].

Agreement Governing the Activities of States on the Moon and Other Celestial Bodies

This agreement recognizes the special status of the Moon in connection with its important role to play in further outer space exploration and prohibits using this celestial body in any conflicts. It also calls to bear in mind the benefits that can be derived from the exploitation of the natural resources of the Moon.

Besides the Moon itself, the Moon Agreement shall also apply to any other celestial bodies, except those that reach Earth by natural means.

One of the most important clauses of the Moon Agreement is that "the exploration and use of the Moon shall be the province of all mankind and shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development" [13]

Also, the Moon Agreement highlights such issues as the limits of permitted actions within the framework of Moon exploration, non-prohibited actions, safeguarding life and health of persons on the Moon, the legal status of the Moon, regime governing the exploitation of the natural resources of the Moon, and free access to all space objects created on the Moon.

As of January 1, 2020, 18 countries ratified and four countries signed the Agreement [17].

The Moon Agreement did not have the necessary support from States, and no countries with the real space power acceded to it. This is mainly due to then-existing contradictions between the US and the USSR, they neither signed nor ratified the Moon Agreement.

Other International Space Treaties

The lack of support for the Moon Agreement from nations made the UN change its approach to international regulation of the outer space exploration and use. The UN Outer Space Committee suggested that the parties should elaborate draft instruments to be approved by the UN General Assembly, which however would not become binding on everyone. As part of this approach, the following instruments have been adopted:

- Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting (1982);
- Principles Relating to Remote Sensing of the Earth from Outer Space (1986);
- Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992);
- Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (1996) [14].

As the names of these documents suggest, they all, except for the last one, govern applied activities in outer space (TV broadcasting and remote sensing) and the use of nuclear energy sources, which are dangerous to human beings and the environment but are required for space exploration.

C. International Space Exploration Organisations

In reviewing the current state of international cooperation in outer space exploration and use, reference should also be made to the activities of international organisations in this domain.

No doubt, the UN plays here a leading role in ensuring the peaceful use of outer space and the fair distribution of the benefits derived from this activity among all countries.

The UN Committee on the Peaceful Uses of Outer Space

The UN Outer Space Committee is the principal UN body to coordinate cooperation between countries and organisations in the exploration and use of outer space. Within the framework of its mandate and functions, this body elaborates development programmes; collects systematizes and discloses data on scientifi research and other activities in outer space; analyses the regulatory issues of space exploration.

To implement its mandated tasks, the UN Outer Space Committee has established two subcommittees:

- the Scientifi and Technical Subcommittee, which aims to coordinate international scientific cooperation in space exploration and space technologies
- the Legal Subcommittee with the aim to accelerate technological development in the designated domain through the elaboration and implementation of legal structures, instruments, and mechanisms.

The UN Outer Space Committee operates in the format of annual meetings held in Vienna (Austria). At such meetings, the reports of the members are considered, the challenges identified are assessed, and the issues addressed by the UN General Assembly are discussed. Other key issues considered by this committee include analysis of law enforcement practice concerning international space treaties, national legislation in the designated domain, and the activities of subjects of international law affecting the use of outer space

The UN Office for Outer Space Affairs

This Offic operates within the UN General Assembly and is engaged in the formulation of policy in outer space activities. The UN Offic for Outer Space Affairs is responsible for the implementation and enforcement of decisions of the UN General Assembly and the UN Outer Space Committee, including the Programme on Space Applications; arranges assistance to developing countries in space technologies; ensures that objects launched into outer space are registered and maintains the appropriate registry [13].

International Committee on Space Research

The International Committee on Space Research (COSPAR) is the first international non-governmental organisation aimed at promoting cooperation in space exploration. The primary COSPAR's objectives:

- promotion of scientific research in the context of using aircra t;

- systematization of the scientific research finding
- addressing political challenges that may accompany the space exploration and use.

European Space Agency

The European Space Agency (ESA) stands out for its close affiliatio with the European Union. The ESA is dedicated to deepen the European community's collaboration in the peaceful exploration of outer space, promote space technologies and their scientific application. Today, the agency's primary objective is to devise and implement a long-term European space strategy and to ensure that national space programmes coordinate with and integrate into this strategy, through implementing appropriate policies and elaborating recommendations for member States [13].

The ESA is of primary interest for its outcome-oriented activities: i.e., direct implementation of the applied research in outer space and participation in the implementation of specific space projects

The European Center for Space Law was established in 1989 under the auspices of the ESA to provide the legal basis for space activities and to ensure information exchange and space law development.

International Astronautical Federation

The International Astronautical Federation (IAF) analyses and resolves technical, socio-political, and legal aspects of the problems related to space flights. The International Academy of Astronautics (IAA) operates within the IAF to promote international cooperation in astronautics, facilitate the implementation of programmes aimed at the development of the aerospace industry, and arranges meritorious awards in astronautics [13].

Other International Space Exploration Organisations

Many international organisations to varying degrees are involved in the exploration, use of and international cooperation in the outer space. The following ones can be distinguished among them:

- Intersputnik – International Organisation of Space Communications (operation of the worldwide satellite communications system);
- Intelsat – International Telecommunications Satellite Organization (development, manufacturing, launch, operation, and maintenance of equipment necessary for international public communications);
- International Civil Aviation Organization (use of space communication and navigation in civil aviation);
- International Telecommunication Union (ensuring international cooperation in the rational use and improvement of all types of communications);
- World Health Organization (international cooperation in space medicine and applying space research findings in medicine on Earth; the use of satellite

data to control environmental pollution and epidemics; mapping for the rapid deployment on the ground);
- International Atomic Energy Agency (defining the operating procedure for the return of a nuclear-powered spacecraft; safe use of nuclear power in space);
- World Meteorological Organization (use of space data and technologies for climate studies, weather forecasting, and preventing and mitigating natural disasters).

D. Conclusions and Future Work

The analysis of the contemporary status of international cooperation in space exploration, which has been carried out through the study of the parties involved, suggests that today the SpaceWay project cannot be implemented by any of the existing international organisations.

On the one hand, a great many such organisations are covering large numbers of space activity aspects. On the other hand, all considered structures approach the problems of space exploration either too abstractedly, covering everything as a whole and developing guidelines for activities in all areas, or too specificall , narrowly focusing on just one direction and developing it.

SpaceWay assumes, in a certain sense, a symbiosis of the approaches. This is based on the very essence and mission of the project. Since the project implementation would affect all of humanity, fundamental principles should be developed, within which the entire project will evolve. However, given the practical focus of SpaceWay, each applied aspect needs to be elaborated and regulated. The combination of the above approaches will inevitably result in the identification of certain patterns and common features of various research areas.

Therefore, for the implementation of the SpaceWay project, it appears that a new, non-typical international organisation is required. This organisation would unite, around a common goal, several groups of members responsible for certain stages or parts of the development, design, creation, construction, and operation of the GPV, and the implementation of ancillary and related projects. At least those countries, within which the GPV take-off and landing site will be located, and entities that could finance or arrange financing of the global project should become members of such an international organisation. An international organisation that would implement SpaceWay must have the characteristics of a corporation, i.e., all members are to take part in making the most important decisions, but delegate operational responsibility to the executive body. At the same time, its bureaucratic component and the time-limit for decisions are to be minimized, because the GPV production itself will be very time-consuming.

The review of the development of international space instruments presented in this paper suggests that, for various reasons, unanimity of the members is quite problematic today. This obstacle poses a serious challenge for humanity as a whole. The space industry is developing quite rapidly through a joint effor

of several highly-developed countries, which will intend to appropriate the benefit from the use of outer space, while the development of universally binding space activities regulations stalled several decades ago. Without international regulations, the countries taking part in space activities would be guided exclusively by their own needs and interests that might harm other countries and perhaps even humanity as a whole.

In such a situation, due to its universal essence and mission, SpaceWay can encourage the unanimity of countries as never reached before. At the same time, the GPV design, creation, construction, and operation would require several fundamentally new international agreements to be elaborated. Today, the crucial issue for all humanity in space exploration is to ensure the long-term, efficient, and safe space activities [13]. This can be implemented, in particular, by revising space treaties, although there are various points of view within the science of international space law that question the need to do so.

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Feasibility Study of the Investment Project “Non-Rocket Near Space Industrialization” as a Tool of Saving Earth’s Biosphere

24.1 Introduction

The authors promoted a hypothesis of the absolute competitive superiority of the space industry at the II International Scientific and Technical Conference “Non-Rocket Space Industrialization: Problems, Ideas, Projects” [1]. It was not about an unconditional competitive superiority, but specifically the case of using the General Planetary Vehicle (GPV) created by engineer A.Unitsky [2]. The GPV is distinguished by unique indicators of energy effi ency, passenger, and carrying capacity on an industrial scale, and, of course, electric traction and low ecological footprint. According to the authors, only GPV will be able to provide geospace transport accessibility to the extent, which will make it possible to open the doors widely to space with its endless resources – energy, raw materials, and cosmic space, as well as missed on the Earth physically unique environmental conditions: zero gravity, deep vacuum, exceptional purity, high, as well as cryogenic, temperatures.

According to the competitive market laws, if one of the market participants succeeds in introducing an innovative and thus much more efficien technology, the rest of the market participants, in order to withstand market competition, will need to introduce the same or another, but no less effective, innovative technologies [3]. And since the GPV, according to the calculations presented in the monograph by A.Unitsky [4], is unparalleled in its efficienc and transportation capacity, sooner or later this particular type of geospace vehicle will be chosen by civilization to implement their further space technocratic development.

The rapid build-up capacity of space industry is the most important factor not only for the investment success of Non-Rocket Near Space Industrialization (NRNSI) project, but also for the earliest achievement of its strategic goal – the competitive elimination of Earth's technosphere branches that negatively aff ct the biosphere. The global scale and, at the same time, the rapid pace of space industrialization introduces high demands on the indicators of economic efficienc and carrying capacity of the GPV.

24.2 Organisational and Legal Terms for NRNSI Project Implementation

The obligatory terms for the full-scale start of the NRNSI project implementation is the consolidation of efforts from the entire mankind. First of all, the broad world community and political, scientific, and business elites must deeply realise the inevitability of the space vector of industrial development. Only after that it will become possible to create an international Consortium under the UN auspices with the necessary membership of the planet equatorial belt countries and as many as possible other country-members, especially with the high economic, scientific-technical potential. To exclude the economic discrimination, the size of the minimum contribution to the Consortium's share capital (SC) must be determined in proportion to the GDP of each participating country-member. Economically underdeveloped and developing country-members, even if they limit themselves to minimal contributions to the SC, should still have a minimum single vote in the Consortium corporate governance bodies. Economically well-developed country-members, like any other country-members, should be able to increase number of their votes in the Consortium corporate governing bodies by means of making additional contributions to the SC at any time and thus to increase their statutory share in the Consortium capital, commensurate with their economic well-being. Thus the size of the Consortium's SC should not be limited, but in order to take into account the time value factor, before any contribution to the SC, the current value of the Consortium's assets (reflecting the current state of the NRNSI project implementation) should be revalued, and all previously made contributions should be indexed. All the measures, taken by the country-member to provide economic support for the national work performers and resource suppliers to the NRNSI project, also should be counted as their property contribution to the SC. The institution of free economic zones of a certain width along the equator line by equatorial belt country-members with the transfer to the Consortium of all their rights on urban planning regulations and on all disposed subsoil within the zones should be evaluated and also taken into account as their property contribution to the SC.

According to the authors, such organisational and legal terms could provide the Consortium with the maximum number of country-members and with

the maximum amount of the gathered share capital, sufficient for the successful NRNSI project implementation.

24.3 Space Industrialization as a New Era of Human Development and a Necessary Step to Save the Earth's Biosphere – Economic Justification

Industry development scenario, with the key vector being directed towards space industrialization, the consistent creation of price-competitive driven industries, namely: geospace transport, space solar power generation, mining and processing of raw materials, and only then – the development of other industrial sectors, these industries, in their current states on Earth, are the most harmful for the environment and require vast majority of the resources, and therefore should be among the first industrial sectors to be transferred to space (or rather, recreated in orbit, and phased down on Earth). It is extremely important that the global consortium would oversee the transition of these driving industries, since only in this case the entrepreneurial factor and its inherent commercial allowances will be excluded – this will allow not to undermine the competitiveness of tariffs for space transport services and space electricity, as well as prices for space-based raw materials.

The basis of power generation sector of the space industry can be made up of space-based solar power station (SBSPS), which are based on the film photovoltaic panels with an area of tens of square kilometres, reflecting the focused sunlight on the receiving device. Part of the solar energy can be converted into electricity for the own needs of the space industry. Another part of the solar energy can be transmitted to Earth in the form of an energy-dense laser beam, which is converted into electricity on the Earth.

The efficienc of SBSPS is determined by the high power of the solar flu of 1,366 W/m^2, while on the Earth's surface, on average, it does not exceed 100 W/m^2 [5]. Therefore, when SBSPS is in use, the cost of fuel is excluded, contributing 50–70 % of the cost in case of thermal or nuclear power plants. The absence of fuel and its combustion products leads to the absence of costs for cleaning or disposing harmful emissions or for the burial of radioactive wastes and outdated contaminated equipment. The simplicity of redirecting an intensive energy generated in form of space beams from one receiving device on Earth to another decreases the cost of trunk line transmission of electricity to various territorial consumers, including those located in remote areas. The simplicity of the technology and the low specific consumption of materials by SBSPS substantially reduce the specific capital costs and, as a result, proportionally minimize depreciation and repair costs. The autonomy of the space technological component of SBSPS, which does not require maintenance and can operate in the absence of service staff, means a significant reduction in labor costs and social contributions.

The cost of SBSPS-generated electricity is projected to be up to six times lower, than the cost of electricity generated on Earth, considering equipment delivery by the rockets [6]. However, taking into account (as compared to rocket carriers), a thousandfold reduction in capital costs when delivering SBSPS equipment to orbit using the GPV, but still considering associated operational costs, the market price of SBSPS-generated electricity is projected to be up to 50–100 times lower, than the price of the electricity generated on Earth.

Relatively low cost of the internal space energy leads to the further reduction of the transportation cost of the GPV system, considering that the system is an electric consumer, as well as a vehicle. These power tariffs will initiate equally inexpensive hydrogen fuel generation from ballast water of the GPV and, later, from the ice, mined on asteroids. Furthermore, deep space exploration will be promoted by the significant reduction in the space power tariffs for goods delivery to orbit with the GPV and associated low-cost hydrogen production.

The idea supports not only near-Earth satellites, including their launching, servicing and utilisation processes. It will be possible to send industrial expeditions to asteroids, provide energy-intensive mining, and processing of rocks in the space, deliver industrial volumes of asteroid mined raw materials to orbit and export part of it to Earth. About 800 asteroids have been counted and explored in the closest orbits to Earth up to date. Furthermore, these asteroids have been studied in sufficient detail and classified by size and elemental composition. It was found, that asteroid with a diameter of 1 km can supply about 30 mln tons of nickel, 1.5 mln tons of cobalt, and 7,500 tons of platinum, with an estimated cost of trillions of USD [7]. The minerals of asteroids and the Moon are characterised by their surface occurrence and, which is more important, by their non-metallic native form. According to the data of the global manufacturer of non-ferrous metals GMK Norilsk Nickel OJSC, the content of useful elements in impregnated (poor) ores is 0.2–1.5 % Ni, 0.3–2 % Cu, and 2–10 g/t of platinum group metals (PGM), and in rich ores the content still does not exceed 2–5 % Ni, 0.3–2 % Cu, and 5–100 g/t PGM. At the same time, it is five times more expensive to mine and enrich 1 ton of nickel from the rich ores in comparison with the poor (impregnated) ores [8]. The difference in costs is correlated with the difference in the concentration of the useful elements. Consequently, the cost of extraction of native metals in space is guaranteed to be less in comparison with Earth processes. The difference is proportional to the concentration difference, which reaches tens of times due to the low mineral concentration of the Earth-based ores.

Space energy generation capacity increase has the highest priority, as it is a strategic task and the material foundation for the further space industrialization. Using the example of the electricity consumption pattern in Russia in 2017, it can be seen that households' appliances use only 14.3 %, the rest of electricity power is consumed by the elements of the technosphere, including mining – 12.4 %; processing industries – 29.2 %; energy sector – 11.7 %; transport and communications – 8.5 %; agriculture – 1.4 %; construction – 1.2 %; and other related consumptions – 16 % [9]. At the initial stages, the newly created space energy industry will face a competitive confrontation with the power industry of Earth, which is primarily based on the hydrocarbon fuels. In addition, it will also supply power to the development of the space industry, which will support the competitive confrontation in the markets of the mining and processing industries of the technosphere. As the Earth's technosphere becomes smaller and the capacities of the space industry grow, the space electric power industry will retain its market, but with reducing its export to the Earth portion and increasing the usage by the space industry.

It is important to consider development of the light industries in the space environment. Such productions have lower energy and resources consumption, so they have lower footprint from the biosphere perspective. However, they require advanced technological processes. It makes space-based manufacturing facilities capable of producing services and goods with signifi antly reduced costs. This is facilitated by the specific conditions of the space environment – weightlessness, vacuum, and purity (no inclusions), easily reached with low resources consumption, high and low temperature environments, and gaseous purity of the environment. These conditions expand technological capabilities and significantly reduce the cost of production and improve quality, allowing producing completely new materials with unique properties.

For example, secondary forces (like surface tension) dominate in space, so molten alloys in weightless conditions automatically acquire the form of a sphere. After that, the desired shape can be obtained by an insignificant efforts of external forces, which can be generated by an acoustic, electromagnetic or electrostatic fields. In addition, the recent advancements in 3D technologies allow not only to automate and robotize the production of almost any product, but also to ensure the alloy's composition and the surface finishing quality. These technologies (by virtue of the described principles of shaping and digital control) enable several innovative technological processes, including remote retooling of production programs, which decrease the downtimes and the cost of manufacturing and reconfiguring of the equipment, and expansion of the product line without additional logistic costs. In addition, the unified form factors of the raw materials used – liquids, plastic masses, wires or powders, distinguish space production. They lead to a smaller number of required technological processes of raw materials and lower logistics costs. Finally, these technologies significantly reduce and, in some cases, eliminate technological waste, and if it occurs, the costs of its disposal in space conditions are also minimal.

Complete robotization and the absence of the human factor (apart from minimizing the payroll and reducing direct costs) can signifi antly expand technological capabilities with usage of more efficient but hazardous or poisonous substances. In the absence of production personnel, there is also no need to solve a number of costly tasks which have no direct impact on the production such as: ergonomics and safety of working conditions, measures to prevent victims in case of industrial accidents, maintenance of the social infrastructure, which accompanies any work of the personnel.

It is a fact, the qualitative competitive advantages of goods and services of industrial space are also associated with specific environmental conditions. Respectively, the relatively worse quality of earth-made goods and services or the high costs to achieve such quality, occur due to the disadvantages of physical conditions on Earth.

Gravity is a major disadvantage of terrestrial production conditions, since majority of solid materials undergo stages of softening or melting during their creation or processing. With the presence of gravity, the plastic or liquid material should be restrained by the walls of the processing vessel. Furthermore, gravity also causes majority of the material's structural defects. In addition, it causes convective currents along temperature gradients in the layers of fluids, which have chaotic nature. It leads to the undesirable structural heterogeneity of materials. If the fluid consists of two or more parts, then gravity, due to the difference in the physical properties of materials, contributes to their separation, preventing creation of a homogeneous structure. The main advantage of composite materials is that they are composed of substances, the physical, chemical, mechanical, and other properties of which complement each other. Under zero gravity conditions in space, separation does not occur, so the composed materials produced in space are homogeneous, have no structural defects, and have substantially better quality indicators.

Chemical purity and rarefaction of the atmosphere are other advantages of the space production conditions. Such level of purity cannot be obtained on Earth, because in relatively small volumes of artificial vacuum, it is impossible to eliminate the uncontrolled effect of accumulation of sputtered materials and impurities on the developed surface of the vacuum equipment and their subsequent reevaporation.

Another advantage of the physical conditions of space for production is the possibility of rapid cooling to ultra-low temperatures, which (especially in combination with the presence of a high vacuum) opens up new ways for technologists to control the phase composition of the produced materials, the degree of their homogeneity, the nature and density of crystal lattice defects.

Weightlessness, vacuum, purity, cryogenic temperatures and other factors open up the widest technological prospects not only for metallurgy, but also for the production of nonmetallic types of structural materials and components, including organic and biologically active substances, which broadens the prospects for pharmaceuticals and bioengineering. Furthermore, new materials with unique properties create technological breakthrough in related industries.

The process of targeted transfer of space technology to other industries started at the end of the last century. Since then, this has already led to a significant increase in the level and quality of life of earthlings and to the return of investments in space programs in the forms of direct or indirect economic effect. According to Bryce Space and Technology, in 2017, the space industry showed a weak growth of 1 % [10]. At the same time, experts from Morgan Stanley, Goldman Sachs, Bank of America, and Merrill Lynch predict, that by 2040, the space industry will have reached 1.1 tln – 2.7 tln USD, i.e., will show an increase by 2.8–7.7 times. Such growth is explained by the expectation of fundamental breakthroughs [11]. These processes include: an increase in the number of market participants and the rocket launches they make; a project of global Internet coverage of the Earth's surface; projects of space solar power plants; mining projects on asteroids, on the Moon, and other celestial bodies; space debris collection projects and many others, recently regularly announced, mainly by US companies. Law H.R.2262 adopted by the US Congress in November 2015, encouraging the commercial development and use of asteroid resources and recognizing the right of US citizens to own asteroid resources that they extract, can be considered as confirmation of the seriousness of the announced intentions.

24.4 Terms for the Attracting Global Investments to the NRNSI Project

Using legal foundation and financial benefits, it is possible to evaluate financia details of the consortium's operation. The Consortium will have to fi ance solely all 100 % of the expenditures to create geospace transport and communication complex – the backbone branch of the entire space industry. It includes the implementation of all scientific-research and experimental design development works (R&D) with the preservation of all rights to the newly created intellectual property. The creation of the GPV and the construction of take-off and landing overpass with all necessary energetic, transportation, and communication infrastructure elements. The equatorial take-off and landing complex will be constructed as the part of the Equatorial Linear City and before the first GPV flight. And the orbital take-off and landing complex will be constructed as the part of the Industrial Space Necklace "Orbit" (ISN "Orbit") as soon as possible after the first GPV flight. The risk for the Consortium to lose share or operating control over the geospace transport system with the GPV must be excluded at any circumstances. For example, such a risk could arise in case of a borrower's default and foreclosure on his property. Therefore, the Consortium should not have the right to attract any loans or other forms of debt financ ng, and the sole source of financing the NRNSI project should be only within its own sh re capital.

The creation of the remaining components of space industry should be financed by a large number of independent NRNSI project participants-investors with their own space projects and investment funds, but this task will require the Consortium to take very cardinal simulating incentive measures.

By 2040 the volume of the future space services market, how it has been estimated by experts before, will reach 1.1 tln – 2.7 tln USD. The existence of such expectations is confirmed by regular announcements about such a breakthrough space projects, where the authors note that the most formidable obstacle is the lack of an effective solution for geospace transportation. Today the cargo and passenger delivery to orbit costs about 10 mln USD/t, while the breakthrough space projects feasibility studies budget for lifting tariff of 1 mln USD/t [1 , 13].

Running ahead, the GPV economy will allow the Consortium to provide all the NRNSI project participants not only with the cherish-dreamt lifting tariff

at 1 mln USD/t, but also with significantly lowered tariff for the route orbit-to-Earth at 0.5 mln USD/t. However, breakthrough space projects, being inherently exclusive, will not be able to ensure a truly global scale and rapid pace of the NRNSI project implementation. The authors consider a partnership scheme as a fundamental Consortium incentive measure to attract as many independent participants-investors as possible. All interested parties may be proposed to transfer to the Consortium at least 50 % of share capital in their space projects in exchange for the additional preferences in the form of 25 and 50-times geospace delivery tariff discounts. As a result, the cargo and passengers partner tariffs will be 40,000 USD/t for lifting and 20,000 USD/t for lowering, while the all 100 % financing of such partner space projects should remain with the partners themselves.

The unit costs for the production of high-tech equipment (for example, a Tesla electric vehicle priced 50,000–75,000 USD and weighing 2–2.5 tons) do not exceed 25,000 USD/t, which indirectly determines the upper level of capital costs for manufacturing any space equipment. Thus, the specific cost of the concession by the Partners of the half of their space projects in favor of the Consortium can be estimated at 12,500 USD/t, while the benefi s obtained from the reduction of the standard to partner tariff will amount to 960,000 USD/t for lifting and 980,000 USD/t for lowering geospace delivery. According to the authors, hardly anyone will refuse such a partnership offe . But these terms of partnership are not yet an offer and they are considered so far only as one of the scenario options.

As an illustration of how the geospace tariff on equipment delivery to orbit affect the total capital costs, cost price and payback period of space projects, an enlarged feasibility study for the creation of a 10 GW SBSPS is presented in Table 1. The cost of electricity in the partner SBSPS will be 0.016 USD/kWh for consumers in space and 0.027 USD/kWh for consumers on Earth. The sale by partner SBSPS of the half of generated electricity to consumers in space at a rate 0.05 USD/kWh and the remaining half – to consumers on Earth at a rate of 0.08 USD/kWh is profitable by 211.1 %, and the simple payback period will be equal to 6.5 years old.

Table 1 – Project of SBSPS with a capacity of 10 GW

Space-based solar power station (SBSPS)	Capital costs	
1	2	3
Specific power of solar luminous flux per 1 ^{2}	1.4	kW/m^2
Efficiency of film solar ce	60	%
Installed capacity of SBSPS	**10**	**GW (mln kW)**
Specific weight of the space part of the SBSPS equipment	10	kg/kW
Weight – components of the space part of SBSPS	**100,000**	**tons**
Specific CAPEX – equipment manufacturin	50,000	USD/t
Creation of the space part of SBSPS	**5**	**bln USD**

The end of Table 1

1			2	3
UP	P	**Geospace transportation tariff**	**40,000**	USD/t
		Delivery to orbit of the space part of SBSPS	**4**	**bln USD**
		Specific CAPEX – installation in spac	2,000	USD/t
		Installation of the space part of SBSPS	**0.2**	**bln USD**
		Unit cost of production on Earth	10	Space parts, %
		Creation of the ground (rectenna) part of SBSPS	**0,5**	**bln USD**
		Total capital expenditures for SBSPS	**9,7**	**bln USD**
		Space-based solar power station (SBSPS)	**Operational expenses**	
		Unit costs – maintenance and repair	3	% of CAPEX
		Unit costs – emergency repair	1	% of CAPEX
		Maintenance and repair of the space part of SBSPS	**0,37**	**bln USD/year**
		Full amortization period – space part of SBSPS	25	years
		Depreciation of the space part of SBSPS	**0.37**	**bln USD/year**
		Unit costs – maintenance and repair	3	% of CAPEX
		Unit costs – emergency repair	1	% of CAPEX
		Maintenance and repair of the ground part of SBSPS	**0.02**	**bln USD/year**
		Full amortization period – onshore part of SBSPS	25	years
		Depreciation of the ground part of SBSPS	**0.02**	**bln USD/year**
		Specific density of operator	5	staff unit/k
		Total number of staff	50	staff uni
		Average level of wages including taxes	50,000	USD/year × staff unit
		Personnel costs	**0.003**	**bln USD/year**
		Full operating costs for SBSPS	**0,78**	**bln USD/year**
		Illumination factor of SBSPS batteries	55 in the Sun, %	
		Annual electricity production in space	**48.18**	**bln kWh/year**
		Generation – antenna – rectenna – network conversion loss	60	Efficiency in
		Reduced power of SBSPS on Earth	**6**	**GW**
		Annual electricity generation on Earth	**28.91**	**bln kWh/year**
		The cost of SBSPS electricity in space	**0.016**	**USD/kWh**
		The cost of SBSPS electricity on Earth	**0.027**	**USD/kWh**

The capital costs for the non-partner SBSPS, which equipment delivered to orbit using standard lifting tariff of 1 mln USD/t, amount to 105.7 bln USD (Table 2a), which even doesn't allow such a project to pay off, as can be seen in Table 2b.

Table 2a – Impact of tariffs on capital cost

Comparison of lifting SBSPS CAPEX					
Price costs S	Consortium C	Partner P	Participant R		
0.3	2	40	1,000	Tariff, thous. USD/	Delivery to orbit
100	99.8	96	0	Discount, %	Effectiv
0.03	0.2	4	100	bln USD	Lifting costs
5.73	5.9	9.7	105.7	bln USD	Total CAPEX
5.4	5.6	9.2	100	%	Saving capital costs
CAPEX – V.S. – RATES					

Table 2b – Impact of tariffs on investment attractivenes

Comparative economy							
Price costs S	Consortium C	Partner P	Participant R	Variant – Partner			
–5.73	–5.9	–9.7	–105.7	–9.7	CAPEX SBSPS, bln USD	Tariff	Share, %
1.2	1.2	1.2	1.2	1.205	Energy in space, bln USD	0.05	50
1.16	1.16	1.16	1.16	1.156	Energy on Earth, bln USD	0.08	50
–0.44	–0.45	–0.76	–8.44	–0.759	OPEX SBSPS, bln USD		
–3.81	–3.99	–8.1	–111.78	–8.098	Net cash flo		
1.92	1.91	1.6	–6.08	1.602	EBITDA, bln USD		
2.98	3.09	6.05	–17.39	6.05	Payback, years		

The abovementioned example displays haw such a low partner's fee for entering space industry will make many breakthrough (and beyond) space projects attractive for investments, and how the amount of investments they need will decrease by many times. In addition, investment funds and banks will inevitably reconsider their attitude to Earth industrial projects that have lost their perspective and redirect their capitals towards space industrial projects, in which such a perspective will grow.

Benefits of the Consortium from the use of such incentive measures are the increased demand for geospace transportation, attraction of plenty of third party investments with the absence of any credit obligations for the Consortium, share and operation control over the majority of the space projects, replenishment of the budget with partner's revenues due to the received 50 % share in partner space projects, as well as a high degree of diversification of NRNSI project participants and thus the formation of a new competitive space market.

Organisations of the UN system have been long active in limiting the anthropogenic oppressing of the Earth's biosphere by technosphere created by mankind. In 1992, the UN Framework Convention on Climate Change was adopted and ratified by 197 states. In 1995, the countries initiated negotiations, and two years later they adopted the Kyoto Protocol, ratified by 192 states, obliging economically developed countries to reduce greenhouse gas emissions. At the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in 2015 in Paris, a landmark agreement was concluded to combat climate change in terms of limiting carbon emissions and further low-carbon development. Considering the above mentioned, and most importantly – the high effi ency of the NRNSI project in achieving the goals of saving the Earth's biosphere and saving the future of civilization, it is quite reasonable to expect the trade and tax preferences.

According to the authors, such investment and economic terms will provide a plenty number of the NRNSI project participants and partners with their own space projects and investments that will provide the NRNSI project with a global scale and a rapid pace of practical implementation.

24.5 Feasibility Study of the NRNSI Project

To create a feasibility study for the effectiveness of the GPV, the initial data were used, determined by the author-developer engineer A. Unitsky in his scientific works, such as [4]:

- weight and dimension characteristics of the GPV are as follows: 30 mln tons of dead weight and 10 mln tons of the maximum cargo and passenger weight both for lifting and the lowering flights;
- the length along the Earth's equator is 40,075 km. The length along low-Earth orbit at an altitude of 400 km is 41,332 km;
- calculation of energy consumption for the lifting the GPV with a full load, as the kinetic energy of the entire GPV structure with a load during its acceleration to the first cosmic velocity (plus 20 % energy reserve), which initially must be supplied to the two flywheels covering the planet equator with initial total weight of 20 mln tons, rotating in a vacuum channel and supported by magnetic levitation;
- the level of energy losses in accordance with the accepted total GPV efficienc is 90 % (this indicator is taken with a large margin, since further optimisation studies show that the overall GPV efficiency can be increased up to 97– %);

- service life of the GPV till the entire amortization period was estimated at 10,000 take-off and landing cycles
- the specific indicator of service personnel is five staff units for each kilometre of the GPV along the equator, as well as the level of annual labor remuneration is 50,000 USD/year. These are also specific construction costs of 25 mln USD/k for 20 % of the land areas and 35 mln USD/km for 80 % of the ocean zones of an equatorial take-off and landing overpass with all require infrastructure.

The feasibility study also considers the abovementioned investment and economic terms, including the ban on the Consortium to attract credit financing and tax exemptions. The standard lifting tariff of 1 mln USD/t for all participants and discounted lifting tariff of 40,000 USD/t for the partners are taken as the release rates for geospace transportation in the calculations. All the lowering tariffs are 50 % of the lifting tariffs Geospace transportation tariffs for the Consortium as a consumer are more favourable and even close to the cost price – 2,000 USD/t for lifting and 1,000 USD/t for lowering. To estimate operating costs (and additional income) related to energy costs, the electricity rate of 0.05 USD/kWh is applied, also for purchase electricity (night tariff) for the GPV flights in the 1st year, and also for selling generated by lowered cargo electricity on the wholesale energy market to technosphere consumers. Starting from the second year of space industrialization, the GPV consumes the electricity, generated by space-based solar power at a partner electricity rate of 0.02 USD/kWh.

Within the framework of the feasibility study, calculations of capital and operating costs and geospace transportation by the GPV cost price were carried out.

The total amount of capital expenditures for the creation of general planetary transport system with the GPV is estimated at 2,204 bln USD, including: R&D – 116 bln USD, the creation of the GPV (with the abovementioned characteristics) – 750 bln USD, the take-off and landing overpass with initial infrastructure – 1,322 bln USD, including the land equator areas – 200 bln USD and the ocean equator areas – 1,122 bln USD. The cost of electricity of the irreducible reserve of the kinetic energy of the flywheels for lifting the weight of the GPV without load is 16 bln USD and also considered as capital costs (Table 3).

Table 3 – Capital costs for creation of the geospace transport system

Geospase transport system	Capital costs	
1	2	3
Costs on R&D	**116**	**bln USD**
Dry (own, unloaded) weight of GPV	30	mln tons
Maximum lifting capacity of GPV	10	mln tons
Maximum take-off weight of GP	40	mln tons
The length of the equatorial overpass	40,076	km
Specific cost (analogue – electric car	25,000	USD/t
The cost of creating of GPV	**750**	**bln USD**

The end of Table 3

1	2	3
The share of the onshore equatorial overpass	20	Perimeter share, %
The length of the onshore equatorial overpass	8,015.2	km
Specific cost of the onshore equatorial overpass sectio	25	mln USD/km
Construction of the onshore equatorial overpass	**200.38**	**bln USD**
The share of the offshore equatorial overpas	80	Perimeter share, %
Length of the offshore equatorial overpas	32,060.8	km
Specific cost of the offshore equatorial overpass secti	35	mln USD/km
Construction of the offshore equatorial overpass	**1,122.13**	**bln USD**
Lifting energy at full load +20 % stock	417.1	bln kWh
The share of energy consumption for lifting the weight of GPV	75	Share of energy costs, %
Share of energy consumption for lifting maximum load	25	Share of energy costs, %
Electricity purchase tariff (night)	**0.05**	**USD/kWh**
The cost of lifting energy for GPV with a full load	20.85	bln USD
Energy costs for lifting GPV without load	**15.64**	**bln USD**
Full capital expenditures for the creation of geospace transport system	**2,204.15**	**bln USD**

The total amount of the GPV operating costs for 50 flights per year with full load for only lifting cargo (which is more typical for the initial stages of space industrialization) is rounded up to 360 bln USD/year, including: expenses for the electricity purchase (at night tariff) for cargo lifting in 261 bln USD/year, electricity losses (with 90 % efficiency in 78 bln USD/year, maintenance and repair costs (specific depreciation per flight) in 11 bln USD/year, and fixed annual labor costs in 10 bln USD/year (Table 4).

Table 4 – Operational expenses of the geospace transport system

Geospase transport system	**Operational expenses**	
1	2	3
Number of scheduled GPV flights per yea	50	flights/yea
Including energy consumption for lifting (–) and lowering (+) cargo	5.21	bln USD/fligh
Energy costs for lifting	**260.69**	**bln USD/year**
Efficiency of electric motor and magnetic suspensi	0.9	%
Electricity losses in % of lifting energy	1.56	bln USD/fligh
Energy loss costs (per full GPV flight)	**78.21**	**bln USD/year**

The end of Table 4

1	2	3
Number of GPV launches during the full depreciation period	10,000	Launches of all
Freight traffic for the entire depreciation peri	100	bln tons
Unit costs for maintenance and repair	0.22	bln USD/fligh
Maintenance and repair costs (depreciation)	**11.02**	**bln USD/year**
Linear density of personnel	5	staff unit/k
Total number of staff	200,380	staff uni
Average level of wages including taxes	50,000	USD/year × staff uni
Unit costs for staff pa	0.2	bln USD/fligh
Staff costs and deductions	**10.02**	**bln USD/year**
Geospace transport system full operating expenses	**359.93**	**bln USD/year**
Specific ene gy costs for lifting (–)/lowering (+) loads	521.37	USD/t
Unit costs for energy losses (lifting/lowering GPV)	156.41	USD/t
Unit costs for maintenance and repair (depreciation)	22.04	USD/t
Unit costs for personnel labor	20.04	USD/t
Price cost of lifting a ton of cargo	**620.62**	**USD/t**
Income (additional) for launching a ton of cargo	**–422.13**	**USD/t**

The cost price of geospace transportation is determined separately for each of the two directions – lifting and lowering. In the case of the lifting cargo into orbit, the cost price is 620 USD/t, taking into account the direct costs of electricity for lifting energy and indirect costs (energy losses, maintenance and repairs, personnel remuneration), in proportion to the share of the lifted cargo to the total (lifted and lowered) cargo per two ways flight. In the case of the lowering cargo from orbit to Earth, the cost price turns to a negative value (means additional income) –422 USD/t, taking into account the income from the sale of generated electricity (recovered) minus indirect costs (energy losses, maintenance and repairs, staff salaries) also in proportion to the share of lowered cargo to the total (lifted and lowered) cargo per two ways fl ght, which in lowering case turned out to be less than the generated income.

The profi ability of the standard lifting tariff of 1 mln USD/t is striking in its values and amounts to 161,000 %, and in the case of the standard lowering tariff of 0.5 mln USD/t. the concept of profitability is not applicable, since the transport service in this direction not only covers its expenditures, but also brings additional incremental income above the tariff. Even in the case of a partner-preferential s lifting tariff of 40,000 USD/t for partners, the profitability is no less striking and amounts to 6,300 %, and in the case of a preferential for partners lowering tariff of 20,000 USD/t, there is also no traditional concept of profitabilit to describe it. Hydroelectric power plant is a direct analogue of the lowering GPV's work – they both transform the potential energy of the water and cargo respectively to kinetic energy, which then generates electric power.

As a part of the feasibility study, an analysis of the sustainability of the cost price indicators for geospace cargo and passenger transportation by the GPV was made for different delivery directions and numbers of full loaded flights per year, as well as for the partial workload of a single flight per year. All modes were analysed – for purchased electricity rate at 0.05 USD/kWh and for partner electricity rate at 0.02 USD/kWh.

For a single GPV flight per year with a full load in both directions using purchased electricity, the lifting and lowering cost price will amount to 1,111 USD/t and 68.8 USD/t, respectively. Already for two such GPV flights per year, the lifting cost price and the negative lowering cost price (means additional incremental income) will already amount to 861 USD/t and negative (profitability –182 USD/t, respectively. And for 50 such GPV flights per year, the lifting cost price and the negative lowering cost price (means additional incremental income) will already amount to 620 USD/t and negative (profi ability) –422 USD/t, respectively. The consumption of space electricity at a reduced rate, will cause an almost proportional decrease of the lifting cost prices so for one, two and 50 GPV fl ghts per year it will amount to 798.7 USD/t, 548.3 USD/t, and 307.8 USD/t, respectively. The consumption of space electricity at reduced tariff does not affec the lowering cost prices, since the GPV at lowering does not consume energy, but generated electricity is always sold at a fixed electricity rate of 0.05 USD/kWh (Table 5).

For a single GPV flight per year with a full load (only in one lifting direction) using purchased electricity, the lifting cost price will amount 1,702 USD/t. Already for two such GPV flights per year, lifting cost price will reach the amount of 843 USD/t. And for 50 such GPV flights per year, the lifting cost price will decline to 720 USD/t. The consumption of space electricity at a reduced rate will cause proportional decrease in the lifting cost prices, so for one, two and 50 GPV flights per year it will be equal to 1,389 USD/t, 530 USD/t, and 407 USD/t, respectively (Table 6).

For a single GPV flight annually with a full load (only in one lowering direction) using purchased energy, the lowering cost price will amount to 659 USD/t. Already for two such GPV flights per year, the lowering cost price will already reach 158 USD/t. Starting from three GPV flights per year, the lowering cost price turns to negative value (additional incremental income) and equal to –9 USD/t. And for 50 such GPV flights per year, the negative lowering cost price (additional incremental income) will amount –323 USD/t. The consumption of space electricity at reduced tariff does not affect the lowering cost prices, since the GPV at lowering does not consume energy, but generated electricity is always sold at a fixed (as per the feasibility study) electricity rate of 0.05 USD/kWh (Table 7).

Table 5 – Influence on the cost of the number of flights per yea – and up and down

		Purchase electric tariff 0.05 USD/kW						Preferential electric tariff 0.02 USD/kW					
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Impact the number of flights per year – lifting only	Number of flights year	**1**	**2**	**5**	**10**	**40**	**50**	**1**	**2**	**5**	**10**	**40**	**50**
Freight traffic – lifting	**mln t/year**	**10**	**20**	**50**	**100**	**400**	**500**	**10**	**20**	**50**	**100**	**400**	**500**
Number of flight per year – up	Flights/ year	1	2	5	10	40	50	1	2	5	10	40	50
Loading the last flight – u	% loading	–	–	–	–	–	–	–	–	–	–	–	–
Freight traffic volume – lowering	**mln t/year**	**10**	**20**	**50**	**100**	**400**	**500**	**10**	**20**	**50**	**100**	**400**	**500**
Number of flight per year – down	Flights/ year	1	2	5	10	40	50	1	2	5	10	40	50
Loading of the last fligh – down	% loading	–	–	–	–	–	–	–	–	–	–	–	–
Gross cargo flow	**mln t/year**	**20**	**40**	**100**	**200**	**800**	**1,000**	**20**	**40**	**100**	**200**	**800**	**1,000**
Number of scheduled flights per yea	Flights/ year	1	2	5	10	40	50	1	2	5	10	40	50
Predominant cargo traffic direction	Up = down	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal

The end of Table 5

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scheduled loading (max 50 flights/year	% of flights year	2	4	10	20	80	100	2	4	10	20	80	100
Operating expenses	**bln USD/ year**	**–11.8**	**–13.59**	**–18.94**	**–27.86**	**–81.4**	**–99.25**	**–8.68**	**–7.33**	**–3.3**	**3.42**	**43.73**	**57.17**
The cost of electrical energy for lifting the load	bln USD/ year	–5.214	–10.427	–26.069	–52.137	–208.549	–260.687	–2.085	–4.171	–10.427	–20.855	–83.42	–104.275
Income when the cargo is lowering	bln USD/ year	5.214	10.427	26.069	52.137	208.549	260.687	5.214	10.427	26.069	52.137	208.549	260.687
Costs of electricity losses	bln USD/ year	–1.564	–3.128	–7.821	–15.641	–62.565	–78.206	–1.564	–3.128	–7.821	–15.641	–62.565	–78.206
Maintenance and repair (depreciation)	bln USD/ year	–0.22	–0.441	–1.102	–2.204	–8.817	–11.021	–0.22	–0.441	–1.102	–2.204	–8.817	–11.021
Personnel costs	bln USD/ year	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019
Cost of geospace transportation	**USD/t**	**1,180.4**	**679.4**	**378.8**	**278.6**	**203.5**	**198.5**	**867.5**	**366.6**	**66**	**–34.2**	**–109.3**	**–114.3**
Cost of casrgo lifting	USD/t	1,111.6	861.1	710.8	660.7	623.1	620.6	798.7	548.3	398	347.9	310.3	307.8
Cost of cargo lowering	USD/t	68.8	–181.7	–332	–382.1	–419.6	–422.1	68.8	–181.7	–332	–382.1	–419.6	–422.1

Table 6 – Influence of the number of flights per year on the pri cost of the lifting only

		Purchase electric tariff 0.05 USD/kW						Preferential electric tariff 0.02 USD/kW					
Impact the number of flights per year – lifting only	**Number of flights/ year**	**1**	**7**	**8**	**20**	**40**	**50**	**1**	**7**	**8**	**20**	**40**	**50**
Freight traffic – lifting	**mln t/ year**	**10**	**70**	**80**	**200**	**400**	**500**	**10**	**70**	**80**	**200**	**400**	**500**
Predominant cargo traffic directi	Up = down	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up	Up
Scheduled loading (max 50 flights year)	% of flights year	2	14	16	40	80	100	2	14	16	40	80	100
Operating expenses	**bln USD/ year**	**–17.02**	**–59.01**	**–66.01**	**–149.98**	**–289.95**	**–359.93**	**–13.89**	**–37.11**	**–40.98**	**–87.42**	**–164.82**	**–203.52**
The cost of electrical energy for lifting the load	bln USD/ year	–5.214	–36.496	–41.71	–104.275	–208.549	–260.687	–2.085	–14.598	–16.684	–41.71	–83.42	–104.275
Income when the cargo is lowering	bln USD/ year	–	–	–	–	–	–	–	–	–	–	–	–
Costs of electricity losses	bln USD/ year	–1.564	–10.949	–12.513	–31.282	–62.565	–78.206	–1.564	–10.949	–12.513	–31.282	–62.565	–78.206
Maintenance and repair (depreciation)	bln USD/ year	–0.22	–1.543	–1.763	–4.408	–8.817	–11.021	–0.22	–1.543	–1.763	–4.408	–8.817	–11.021
Personnel costs	bln USD/ year	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019
Cost of geospace transportation	**USD/t**	**1,701.7**	**843**	**825.1**	**749.9**	**724.9**	**719.9**	**1,388.9**	**530.1**	**512.2**	**437.1**	**412.1**	**407**

Table 7 – Influence of the number of flights per year on the pri cost of the lowering only

Impact the number of flights per year – lowering only	Number of flights/year	Purchase electric tariff 0.05 USD/kW						Preferential electric tariff 0.02 USD/kW					
		1	**2**	**3**	**10**	**45**	**50**	**1**	**2**	**3**	**10**	**45**	**50**
Freight traffic volume – lowering	**mln t/year**	**10**	**20**	**30**	**100**	**450**	**500**	**10**	**20**	**30**	**100**	**450**	**500**
Predominant cargo traffic directi	Up = down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down
Scheduled loading (max 50 flights/year	% of flights year	2	4	6	20	90	100	2	4	6	20	90	100
Operating expenses	**bln USD/ year**	**–6.59**	**–3.16**	**0.27**	**24.27**	**144.29**	**161.44**	**–6.59**	**–3.16**	**0.27**	**24.27**	**144.29**	**161.44**
The cost of electrical energy for lifting the load	bln USD/ year	–	–	–	–	–	–	–	–	–	–	–	–
Income when the cargo is lowering	bln USD/ year	5.214	10.427	15.641	52.137	234.618	260.687	5.214	10.427	15.641	52.137	234.618	260.687
Costs of electricity losses	bln USD/ year	–1.564	–3.128	–4.692	–15.641	–70.385	–78.206	–1.564	–3.128	–4.692	–15.641	–70.385	–78.206
Maintenance and repair (depreciation)	bln USD/ year	–0.22	–0.441	–0.661	–2.204	–9.919	–11.021	–0.22	–0.441	–0.661	–2.204	–9.919	–11.021
Personnel costs	bln USD/ year	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019
Cost of geospace transportation	**USD/t**	**659**	**158**	**–9**	**–242.7**	**–320.7**	**–322.9**	**659**	**158**	**–9**	**–242.7**	**–320.7**	**–322.9**

For a single GPV flight per year, loaded in both lifting and lowering directions, but loaded only at 10 % of its full workload, the increased delivery cost prices will amount to 6,423 USD/t for lifting and 5,380 USD/t for lowering. For a single GPV flight per year, loaded in both lifting and lowering directions, but loaded only at 2 % of its full workload, the increased delivery cost prices will amount to 30,030 USD/t for lifting and 28,824 USD/t for lowering. For a single GPV flight per year, loaded in both lifting and lowering directions, but loaded only at 1 % of its full workload, the increased delivery cost prices will amount to 59,539 USD/t for lifting and 58,496 USD/t for lowering. Note, that the lifting cost price 59,539 USD/t for such a low as 1 % load of the GPV is still almost 17 times lower than the standard lifting tariff 1 mln USD/t (able 8).

As a part of the feasibility study, an analysis of the investment attractiveness of the NRNSI project was carried out on the basis of an analysis of investment, operating and financial cash flo , as well as net present value. To carry out this analysis, additional volumetric-temporal reference data were used, also determined by the engineer A. Unitsky in a number of his scientific works [4]. This is a 20-year preparatory period with a schedule for the annual distribution of total capital expenditures for R&D, for the creation of the GPV and for the construction of an equatorial overpass with the necessary infrastructure. And this is a 21-year period of space industrialization with a schedule of annual number of cargo flights and freight traffic in both directions

The analysis of investment attractiveness was carried out for two demand options. In both options, the volume of annual number of cargo flights and freight traffic in both directions remains the same and meets the same practical objectives of the NRNSI project. But in the firs , pessimistic scenario, due to the almost complete absence of demand from the third-party participants, the Consortium itself is forced to act as the customer for 97.5 % of all geospace transportation, need to achieve all the practical objectives of the NRNSI project, but it uses both delivery tariffs close to the cost price – 2,000 USD/t for lifting and 1,000 USD/t for lowering. And only 2.5 % of geospace transportation is carried out by partners who also use discounted tariffs. For better comprehension of Table 9, the array of data for a long 41-year period were grouped into periods of fiv years each.

Gross capital expenditures, including the expert assessment of the capital costs of the ISN "Orbit" of 925 bln USD (with a weight of 150 mln tons), will amount to 3,125 bln USD. The proceeds from the sale of the geospace GPV delivery services and from the commissioning of ISN "Orbit" linear segments (long-term rental for industrial cluster development) will amount to 36,350 bln USD. Due to the large share of the lowering cargo-passenger traffi from orbit to the Earth, all the GPV operation expenses are fully covered by the extraordinary income from the sale of electricity generated by the cargo lowering – as a result, an incremental income of 2,195 bln USD was received. The gross operating cash flow will amount to 38,540 bln USD.

Table 8 – Influence of the level of workload on the cost of just one flight per yea

		Purchase electric tariff 0.05 USD/kW						Preferential electric tariff 0.02 USD/kW					
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Impact of under loading of one flight per year	**% of flight load**	**100**	**80**	**10**	**2**	**1.5**	**1**	**100**	**80**	**10**	**2**	**1.5**	**1**
Freight traffic – lifting	**mln t/year**	**10**	**8**	**1**	**0.2**	**0.15**	**0.1**	**10**	**8**	**1**	**0.2**	**0.15**	**0.1**
Number of flight per year – up	Flights/year	1	1	1	1	1	1	1	1	1	1	1	1
Loading the lastfligh – up	% loading	–	80	10	2	1.5	1	–	80	10	2	1.5	1
Freight traffic volume – lowering	**mln t/year**	**10**	**8**	**1**	**0.2**	**0.15**	**0.1**	**10**	**8**	**1**	**0.2**	**0.15**	**0.1**
Number of flight per year – down	Flights/year	1	1	1	1	1	1	1	1	1	1	1	1
Loading of the last fligh – down	% loading	–	80	10	2	1.5	1	–	80	10	2	1.5	1
Gross cargo flow	**mln t/year**	**20**	**16**	**2**	**0.4**	**0.3**	**0.2**	**20**	**16**	**2**	**0.4**	**0.3**	**0.2**
Number of scheduled flights per yea	Flights/year	1	1	1	1	1	1	1	1	1	1	1	1
Predominant cargo traffic direction	Up = down	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal	Equal

The end of Table 8

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scheduled loading (max 50 flights year)	% of flights year	2	2	2	2	2	2	2	2	2	2	2	2
Earth tariff	kWh	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Space tariff	kWh	–	–	–	–	–	–	0.02	0.02	0.02	0.02	0.02	0.02
Operating expenses	**bln USD/ year**	**–11.8**	**–11.8**	**–11.8**	**–11.8**	**–11.8**	**–11.8**	**–8.68**	**–9.3**	**–11.49**	**–11.74**	**–11.76**	**–11.77**
The cost of electrical energy for lifting the load	bln USD/ year	–5.214	–4.171	–0.521	–0.104	–0.078	–0.052	–2.085	–1.668	–0.209	–0.042	–0.031	–0.021
Income when the cargo is lowering	bln USD/ year	5.214	4.171	0.521	0.104	0.078	0.052	5.214	4.171	0.521	0.104	0.078	0.052
Costs of electricity losses	bln USD/ year	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564	–1.564
Maintenance and repair (depreciation)	bln USD/ year	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22	–0.22
Personnel costs	bln USD/ year	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019	–10.019
Cost of geospace transportation	**USD/t**	**1,180.4**	**1,475.4**	**11,803.5**	**59,017.7**	**78,690.2**	**118,035.4**	**867.5**	**1,162.6**	**11,490.7**	**58,704.9**	**78,377.4**	**117,722.5**
Cost of casrgo lifting	USD/t	1,111.6	1,259.1	6,423.1	30,030.2	39,866.5	59,539.1	798.7	946.3	6,110.3	29,717.4	39,553.7	59,226.2
Cost of cargo lowering	USD/t	68.8	216.3	5,380.4	28,987.5	38,823.7	58,496.3	68.8	216.3	5,380.4	28,987.5	38,823.7	58,496.3

Table 9 – Analysis of cash flows for the option of no external deman

		Volume, structure and dynamic of demand			2020–2039	2040	2041–2045	2046–2050	2051–2055	2056–2060
		1	2	3	4	5	6	7	8	9
		Freight traffic – lift	**4,100**	**mln t**	**–**	**100**	**1,900**	**1,100**	**500**	**500**
		Number of flights per year – u	410	Flights	–	10	190	110	50	50
		Freight traffic volume – lowering	**7,810**	**mln t**	**–**	**10**	**750**	**2,050**	**2,500**	**2,500**
		Number of flights per year – dow	781	Flights	–	1	75	205	250	250
		Gross cargo flow	**11,910**	**mln t**	**–**	**110**	**2,650**	**3,150**	**3,000**	**3,000**
		Number of scheduled flights per yea	915	Flights	–	10	190	215	250	250
		Predominant cargo traffic	Down	Up = down	–	Up	Up	Down	Down	Down
		Loading by tonnage of flights performed	**65.39**	**%**	**–**	**11**	**53**	**63**	**60**	**60**
		Loading by tonnage maximum number of flights	**56.71**	**%**	**–**	**11**	**53**	**63**	**60**	**60**
		Loading by number of flights	**87.14**	**%**	**–**	**20**	**76**	**86**	**100**	**100**
		Average value – cost								
UP	S	Cost of cargo lifting	299.63	USD/t	–	774.69	292.653	282.777	295.753	295.753
D	S	Cost of cargo lowering	–437.92	USD/t	–	–268.06	–437.269	–447.145	–434.17	–434.17
		Tariff scale – cargo lifting								
UP	C	Consortium tariff	2,000	USD/t, %	–	97.5	97.5	97.5	97.5	97.5
UP	P	Partner tariff	40,000	USD/t, %	–	2.5	2.5	2.5	2.5	2.5
UP	R	Participant tariff	1,000,000	USD/t, %		0	0	0	0	0
		Tariff scale – cargo lowering								
D	C	Consortium tariff	1,000	USD/t, %	–	97.5	97.5	97.5	97.5	97.5
D	P	Partner tariff	20,000	USD/t, %	–	2.5	2.5	2.5	2.5	2.5
D	R	Participant tariff	500,000	USD/t, %	–	0	0	0	0	0

The continue of Table 9

	1	2	3	4	5	6	7	8	9
	Cash flow – investment			2020–2039	2040	2041–2045	2046–2050	2051–2055	2056–2060
	Proceeds from the sale of assets		**bln USD**						
	Investment expenses in assets	**–3,124.7**	**bln USD**	**–2,186**	**–477.172**	**–461.531**	**–**	**–**	**–**
	R&D, GPV, overpass, infrastructure, other	–116	bln USD	–116	–	–	–	–	–
	General Planetary Vehicle	–765.64	bln USD	–750	–15.641	–	–	–	–
	Equatorial launch overpass and infrastructure	–1,320	bln USD	–1,320	–	–	–	–	–
	Industrial Space Necklace and infrastructure	–923.06	bln USD	–	–461.531	–461.531	–	–	–
	Balance of received and paid dividends	**–**	**bln USD**	**–**	**–**	**–**	**–**	**–**	**–**
	Balance of cash flows (invest-ment)	**–3,124.7**	**bln USD**	**–2,186**	**–477.172**	**–461.531**	**–**	**–**	**–**
	Cash flows – operating			2020–2039	2040	2041–2045	2046–2050	2051–2055	2056–2060
100 %	**Revenue from the sale of products/services**	**36,345.88**	**bln USD**	**–**	**309.75**	**9,391.49**	**9,619.05**	**8,512.8**	**8,512.8**
33.3 %	**Including lifting services**	**12,095**	**bln USD**	**–**	**295**	**5,605**	**3,245**	**1,475**	**1,475**
22 %	For the Consortium	7,995	bln USD	–	195	3,705	2,145	975	975
11.3 %	For partners	4,100	bln USD	–	100	1,900	1,100	500	500
0 %	For participants	–	bln USD	–	–	–	–	–	–
31.7 %	**Including the services of lowering cargo**	**11,519.75**	**bln USD**	**–**	**14.75**	**1,106.25**	**3,023.75**	**3,687.5**	**3,687.5**
21 %	For the Consortium	7,614.75	bln USD	–	9.75	731.25	1,998.75	2,437.5	2,437.5

The end of Table 9

	1	2	3	4	5	6	7	8	9
10.7 %	For partners	3,905	bln USD	–	5	375	1,025	1,250	1,250
0 %	For participants	–	bln USD	–	–	–	–	–	–
	Including rent ISN "Orbit" for building	**12,731.13**	**bln USD**	–	–	**2,680.237**	**3,350.297**	**3,350.297**	**3,350.297**
100 %	**Expenses (energy, raw materials, payroll, %, taxes, etc.)**	**2,191.66**	**bln USD**	–	**–74.79**	**–216.06**	**607.41**	**937.55**	**937.55**
–40.4 %	The cost of electrical energy for lifting the load	–886.33	bln USD	–	–52.137	–396.244	–229.404	–104.275	–104.275
185.8 %	Income from the generation of electricity when carrying cargo	4,071.93	bln USD	–	5.214	391.03	1,068.816	1,303.434	1,303.434
–26.5 %	Costs of electricity losses	–581.85	bln USD	–	–15.641	–118.873	–134.514	–156.412	–156.412
–9.2 %	Maintenance and repair costs (depreciation)	–201.68	bln USD	–	–2.204	–41.879	–47.389	–55.104	–55.104
–9.6 %	Personnel costs	–210.4	bln USD	–	–10.019	–50.095	–50.095	–50.095	–50.095
	Balance of cash flows (operating)	**38,537.54**	**bln USD**	–	**234.96**	**9,175.43**	**10,226.46**	**9,450.34**	**9,450.34**
	Analysis of gross cash flows	**NPV**	**20 %**	**2020–2039**	**2040**	**2041–2045**	**2046–2050**	**2051–2055**	**2056–2060**
	Balance of all cash flows	**35,412.83**	**bln USD**	**–2,186**	**–242.21**	**8,713.9**	**10,226.46**	**9,450.34**	**9,450.34**
	Discounted cash flow	**53.62**	**bln USD**	**–158.991**	**–6.32**	**120.12**	**65.43**	**23.81**	**9.57**
			Period number	19	20	25	30	35	40

Net cash flow as the sum of net investment, operating, and financial cash flows (PV) will amount to 35,415 bln USD. And the net present value (NPV) of that cash flow with a discount rate of 20 % will amount to 54 bln USD.

Thus, even in the case of almost completely absent demand from the third-party participants and when the minimum tariffs close to the cost price are applied, the NRNSI project still demonstrates break-even level.

In the second, optimistic, scenario, the customers of the most of all geospace transportation, due to the plentiful demand, will be the numerous participants who use highly profitable standard tariffs of 1 mln USD/t for lifting and 0.5 mln USD/t for lowering, and equal cargo traffi of partners using preferential, but rather highly profi able, tariffs of 40,000 USD/t for lifting and 20,000 USD/t for lowering. In this scenario, the Consortium will lift the ISN "Orbit" structures totally weighing 150 mln tons within first two years of space industrialization, and then about only 5 % of the total cargo and passenger freight traffi will be reserved to the Consortium as a customer (Table 10).

Given the demand from the numerous participants and partners, the NRNSI project demonstrates high level of investment attractiveness. Gross capital expenditures (including the cost of creating the ISN "Orbit") will amount to the same, as previous 3,125 bln USD. The proceeds from the sale of the geospace GPV delivery services and from the commissioning of the ISN "Orbit" linear segments will grow up to 3,900,000 bln USD. Due to the invariability of cargo (and also lowering) traffic and the electricity rate for the sale of electricity generated by lowering cargo, the NRNSI project will receive the same additional incremental income, as in pessimistic scenario – 2,195 bln USD. Net cash flow as the sum of net investment, opera space-based ting and financial cash flows (PV) will increase and amount to 3,900,000 bln USD. And NPV of that cash flow at a discount rate of 20 %, will also increase up to 25,600 bln USD.

With regard to both scenarios, during the 21 years of practical period of space industrialization, 915 GPV flights will be performed, which will carry 11,910 mln tons of cargo and passengers, including: 4,100 mln tons, delivered from Earth to orbit, and another 7,810 mln tons, delivered from orbit to Earth. At the same time, the GPV flight number effectiveness will amount to 87.15 % of potential number of 50 flights per year. The GPV freight effectiveness will amount to 56.71 % and 65.39 % of the potential freight volumes – full loaded of all planned GPV flight and of all potential GPV flights (50 per year), respectivel .

Thus, with the presence of plentiful demand, the NRNSI project demonstrates an extremely high level of economic efficienc and, even with its almost complete absence, maintains a break-even level.

The geospace transport system with GPV owes unique technical and economic indicators of effi ency due to the incredibly high energy efficienc of the entire complex of technical solutions applied in the GPV principle of operation and structural design by engineer A. Unitsky 40 years ago.

Table 10 – Analysis of cash flows for the option of high external deman

		Volume, structure and dynamic of demand			2020–2039	2040	2041–2045	2046–2050	2051–2055	2056–2060
		1	2	3	4	5	6	7	8	9
		Freight traffic – lift	**4,100**	**mln t**	**–**	**100**	**1,900**	**1,100**	**500**	**500**
		Number of flights per year – u	410	Flights	–	10	190	110	50	50
		Freight traffic volume – lowering	**7,810**	**mln t**	**–**	**10**	**750**	**2,050**	**2,500**	**2,500**
		Number of flights per year – dow	781	Flights	–	1	75	205	250	250
		Gross cargo flow	**11,910**	**mln t**	**–**	**110**	**2,650**	**3,150**	**3,000**	**3,000**
		Number of scheduled flights per yea	915	Flights	–	10	190	215	250	250
		Predominant cargo traffic	Down	Up = down	–	Up	Up	Down	Down	Down
		Loading by tonnage of flights performed	**65.39**	**%**	**–**	**11**	**53**	**63**	**60**	**60**
		Loading by tonnage maximum number of flights	**56.71**	**%**	**–**	**11**	**53**	**63**	**60**	**60**
		Loading by number of flights	**87.14**	**%**	**–**	**20**	**76**	**86**	**100**	**100**
		Average value – cost								
UP	S	Cost of cargo lifting	299.63	USD/t	–	774.69	292.653	282.777	295.753	295.753
D	S	Cost of cargo lowering	–437.92	USD/t	–	–268.061	–437.269	–447.145	–434.17	–434.17
		Tariff scale – cargo lifting								
UP	C	Consortium tariff	2,000	USD/t, %	–	75	11.5	5	5	5
UP	P	Partner tariff	40,000	USD/t, %	–	12.5	44.25	47.5	47.5	47.5
UP	R	Participant tariff	1,000,000	USD/t, %	–	12.5	44.25	47.5	47.5	47.5
		Tariff scale – cargo lowering								
D	C	Consortium tariff	1,000	USD/t, %	–	5	5	5	5	5
D	P	Partner tariff	20,000	USD/t, %	–	47.5	47.5	47.5	47.5	47.5
D	R	Participant tariff	500,000	USD/t, %	–	47.5	47.5	47.5	47.5	47.5

The continue of Table 10

	1	2	3	4	5	6	7	8	9
	Cash flow – investment			**2020–2039**	**2040**	**2041–2045**	**2046–2050**	**2051–2055**	**2056–2060**
	Proceeds from the sale of assets		**bln USD**						
	Investment expenses in assets	**–3,124.7**	**bln USD**	**–2,186**	**–477.172**	**–461.531**	–	–	–
	R&D, GPV, overpass, infrastructure, other	–116	bln USD	–116	–	–	–	–	–
	General Planetary Vehicle	–765.64	bln USD	–750	–15.641	–	–	–	–
	Equatorial launch overpass and infrastructure	–1,320	bln USD	–1,320	–	–	–	–	–
	Industrial Space Necklace and infrastructure	–923.06	bln USD	–	–461.531	–461.531	–	–	–
	Balance of received and paid dividends	–	**bln USD**	–	–	–	–	–	–
	Balance of cash flows (investment)	**–3,124.7**	**bln USD**	**–2,186**	**–477.172**	**–461.531**	–	–	–
	Cash flows – operating			**2020–2039**	**2040**	**2041–2045**	**2046–2050**	**2051–2055**	**2056–2060**
100 %	**Revenue from the sale of products/services**	**3,898,071.63**	**bln USD**	**–**	**15,620.5**	**1,093,087.74**	**1,053,312.8**	**868,025.3**	**868,025.3**
50.2 %	**Including lifting services**	**1,955,880**	**bln USD**	–	**13,150**	**905,120**	**543,510**	**247,050**	**247,050**
0 %	For the Consortium	680	bln USD	–	150	320	110	50	50
1.9 %	For partners	75,200	bln USD	–	500	34,800	20,900	9,500	9,500
48.2 %	For participants	1,880,000	bln USD	–	12,500	870,000	522,500	237,500	237,500
49.5 %	**Including the services of lowering cargo**	**1,929,461**	**bln USD**	–	**2,470.5**	**185,287.5**	**506,452.5**	**617,625**	**617,625**
0 %	For the Consortium	390.5	bln USD	–	0.5	37.5	102.5	125	125

The end of Table 10

	1	2	3	4	5	6	7	8	9
1.9 %	For partners	74,195	bln USD	–	95	7,125	19,475	23,750	23,750
47.6 %	For participants	1,854,875	bln USD	–	2,375	178,125	486,875	593,750	593,750
	Including rent ISN "Orbit" for building	**12,731.13**	**bln USD**	–	–	**2,680.237**	**3,350.297**	**3,350.297**	**3,350.297**
100 %	**Expenses (energy, raw materials, payroll, %, taxes, etc.)**	**2,191.66**	**bln USD**	–	**–74.79**	**–216.06**	**607.41**	**937.55**	**937.55**
–40.4 %	The cost of electrical energy for lifting the load	–886.33	bln USD	–	–52.137	–396.244	–229.404	–104.275	–104.275
185.8 %	Income from the generation of electricity when carrying cargo	4,071.93	bln USD	–	5.214	391.03	1,068.816	1,303.434	1,303.434
–26.5 %	Costs of electricity losses	–581.85	bln USD	–	–15.641	–118.873	–134.514	–156.412	–156.412
–9.2 %	Maintenance and repair costs (depreciation)	–201.68	bln USD	–	–2.204	-41.879	-47.389	-55.104	-55.104
–9.6 %	Personnel costs	–210.4	bln USD	–	–10.019	-50.095	-50.095	-50.095	-50.095
	Balance of cash flows (operating)	**3,900,263.29**	**bln USD**	–	**15,545.71**	**1,092,871.68**	**1,053,920.21**	**868,962.84**	**868,962.84**
	Analysis of gross cash flows	**NPV**	**20 %**	**2020–2039**	**2040**	**2041–2045**	**2046–2050**	**2051–2055**	**2056–2060**
	Balance of all cash flows	**3,897,138.58**	**bln USD**	**–2,186**	**15,068.54**	**1,092,410.15**	**1,053,920.21**	**868,962.84**	**868,962.84**
	Discounted cash flow	**25,562.51**	**bln USD**	**–158.991**	**393.05**	**15,350.53**	**6,908.45**	**2,189.55**	**879.93**
			Period number	19	20	25	30	35	40

24.6 Conclusions and Future Work

Feasibility study results and their analysis show that the geospace transport system with the GPV is not only able to provide the planetary scale and the rapid pace of the Non-Rocket Near Space Industrialization project implementation, but also has significant reserves in economic efficiency and in lifting perf ance.

Such incredibly high efficienc and performance characteristics of the geospace transportation system with the GPV, representing the real sector of economy and the backbone branch of the future space industry, make it possible to consider the highly profitable geospace delivery obligations of the GPV as a financial instrument (for example, a token) to attract investments for financial planning and implementation stages of the NRNSI project.

At the same time, the planetary scale and rapid pace of the practical implementation of the NRNSI project during the period of several last years of preparation stage (before the GPV start) and period of several first years of space industrialization (after the GPV start), will create a significant surge in demand, comparable to the annual growth rate of the technosphere at a very wide range of industrial products and services. These are electricity, ferrous and non-ferrous metals, construction and building materials, chemical and petrochemical products, cable industry products, industrial, transport, road construction and other mechanical engineering industries, electrical and electronic products, as well as the need for hundreds of thousands of highly qualified personnel with the latest knowledge and skills

Therefore, the subject of the next study should be a feasibility study of the preparatory period of the NRNSI project.

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25

Justification of the Economic and Socio-Political Effectiveness of the SpaceWay Subprogramme for Participating Countries

25.1 Introduction

The development of scientifi and technological progress has determined the technogenic nature of modern civilization and led to several dangerous crisis phenomena: progressive depletion of natural resources, pollution of natural environment and biosphere degradation.

Already in the 1960s and 1970s environmental problems have become global, this is associated with severe environmental changes of global concerns [1]. Numerous programmes were commenced to stabilized the situation regarding each environmental problem as summarised in Table 1.

Table 1 – Main environmental problems and programmes for current situation stabilization [1]

Problem	Programme for situation stabilization
1	2
Depletion of natural resources, atmosphere contamination	United Nations Environmental Programme (UNEP) (December 15, 1972) [2]
Loss of biodiversity	United Nations Convention on Biological Diversity (June 5, 1992) [3]

The end of Table 1

1	2
Greenhouse effect, drastic global warming	United Nations Framework Convention on Climate Change (May 9, 1992) [4]
Ozone layer depletion	Vienna Convention for the Protection of the Ozone Layer (March 22, 1985) [5]. Montreal Protocol on Substances that Deplete the Ozone Layer (September 16, 1987) [6]
Hydrosphere pollution, ecological state of the world ocean, the problem of providing humanity with fresh water	United Nations Conference on Environment and Development (UNCED) (June 3–14, 1992) [7]
Land degradation	International Union for Conservation of Nature (IUCN) (active work since October 1948) [8]
Technogenic accidents	United Nations Industrial Development Programme (UNIDO) (1985) [9]

Despite the stabilization measures taken with respect to the environmental situation, the process of large-scale technological development leads human civilization to the point of no return.

The Global Risks Report 2020, prepared by the World Economic Forum with the support of Marsh & McLennan, revealed the challenges for the most serious threats that may affect the world during the next decade, the most likely risks that threaten the planet are related to the ecology [10].

Main safety risks include extreme weather events that lead to the loss of life and property damage; failure of climate change mitigation policies implemented by individual governments and large companies; anthropogenic damage to the environment and environmental crimes, biodiversity loss, and ecosystems destruction; as well as major natural disasters such as earthquakes, tsunamis, volcanic eruptions, and geomagnetic storms [11].

The impossibility of creating isolated technological cycles in the industry determines the only possible solution which is the need to provide technosphere with an ecological niche outside of the biosphere, i.e., in space [12].

Already at the beginning of the 20th century K. Tsiolkovsky justified the necessity of space industrialization in his publications and formulated a plan for space exploration in 16 stages [13]. Many achievements in space exploration have been accomplished up to now (launch of an artificial satellite, human space flight, landing on the Moon, the mission to Jupiter, the launch of a space telescope, landing on Mars, launch and operation of the International Space Station), but the goods delivery volume to the orbit is still very low and it is sighnificantly below a thousand tons per year. It is obvious that large-scale space exploration and transfer of the Earth industry into the orbit will require geocosmic transportation in the amounts of many millions of tons per year, and existing solutions are unable to provide the required transportation capacity. Besides, the cost of payload delivery to a given orbit should be hundreds, if not thousands, of times lower than the current costs, and the process of spacewalking itself should not have a negative impact on the ecology. Therewith, the project of the outer space industrialization requires the operation of a completely new productive, environmentally friendly and efficie transport.

This type of transport was developed by engineer A. Unitsky more than 40 years ago and it is the General Planetary Vehicle (GPV) [12]. Due to its technical design, the project will directly aff ct the territory of countries located along the equator, and this implies the political and social consent of these countries to create a geocosmic transport and infrastructure complex on their territory. Mutual agreement between society and state regarding establishment of the GPV can be achieved by explaining the possible benefits resulting from implementation of the new promising development directions. At the same time, the correct information delivery by the authorities to the population about possible outcomes of the programme implementation, development of the relevant government support programmes and incentives for participants will help to convince the citizens of need for their assistance in the GPV establishment process. Furthermore, the authorities participation in the project which will provide significant growth of life quality is bound to increase public confidence in the authorities and it will lead to an increment in the human productivity. Hereafter, it will create further improvement of well-being and effective socio-political interaction between society and government.

Improving of the population life quality is the most important goal of any state social policies. The authors esteemed the current living standards in the equatorial countries having used the Human Development Index, which is a comprehensive indicator that takes into account the economic situation in the country (in terms of gross national income per capita), literacy rate and life expectancy [14]. The analysis of the human development level showed the potential for life quality improving in the countries with a high level of human development (Brazil, Ecuador, Gabon, Indonesia, Colombia, Maldives), as well as the possibility to stabilize the situation in countries with a low level of human development (the Democratic Republic of the Congo, Uganda, Somalia) [15].

It is also necessary to achieve socio-political satisfaction in several countries: almost half of the countries located along the equator are on the threshold of the government institutions degradation, expressed in inability of the authorities to control the integrity of their territory, as well as demographic, political, and economic situation in the country (critical level of instability according to the Fragile States Index) [16].

The relevance of this issue lies in the fact that the implementation of a global innovation project for space industrialization using the GPV will improve the life quality and the socio-political situation in the participating countries.

This research aims to identify promising directions which will be successful due to the establishment and effecti e operation of the GPV within the countries territories, that in turn will ensure rapid and large-scale economic growth along with increasing socio-political satisfaction and social cohesion.

25.2 The GPV General Characteristics and Research Methods

The General Planetary Vehicle is a reusable geocosmic transport and infrastructure complex for non-rocket exploration of near space with the purpose of the near-Earth space industry creation and operation. The GPV can transport cargo to various circular equatorial orbits, using only the internal forces of the system due to the inalterability of its centre-of-gravity position in space, so it is the only possible eco-friendly system for geocosmic transportation from the standpoint of the laws of physics.

The GPV establishment includes three main stages (steps) which should be carried out in parallel.

1. Research and development work on:

- equatorial launching overpass;
- infrastructure, i.e., transport, logistics, industrial, residential, energy, and information means;
- General Planetary Vehicle;
- transport infrastructural and industrial complex in orbit, including new space industries: industrial, residential, energy, and information ones.

2. Preparation and establishment (construction) of the equatorial launching overpass combined with Unitsky String Tecnology (UST) transport system, as well as buildings, structures, infrastructure (industrial and residential complexes, power plants, power lines, control and communication systems, etc.).
3. Manufacturing and installation of the General Planetary Vehicle (length – 40,076 km; total weight without payload – 30 mln tons), that will be followed by its commissioning [12].

The establishment of the GPV is a global programme in implementation of which all humankind should be involved, however, the territorial aspect of the launching overpass location makes participation of the equatorial countries essential for the project success.

The following scientific methods were used in the course of the present research: system analysis, analogy and modeling, abstraction, and hypothetical method.

25.3 Review of Experience in Large-Scale Projects Implementing

Implementation of any global innovation project requires support of authorities and society. It is often the case that the project which is more profitabl and provides improved safety in comparison with existing solutions can not be implemented for a long time because of mistrust in its possible results or society resistance.

Using the example of the society behaviour at the beginning of the first oil pipelines construction (i.e., one of the large-scale implemented technical projects which has territorially affected a lot of countries), we managed to identify the essential requirements that must be considered in the process of the GPV establishment.

The world's first 8 km long oil pipeline was built in the United States of America in 1865 according to the S. Syckle project, although the idea of transporting oil using pipelines was already expressed by S. Karns in 1860. In July – August 1861 E. Shippen put forward his project on constraction of a 10 km long oil pipeline from the oilfield in the river Oil Creek valley to Oil City (Pennsylvania). However, despite the urgent question of the transport infrastructure expanding, the idea of constructing a pipeline was accepted halfheartedly by the wells owners. The Philadelphia capitalists also had no interest in financing this project because they believed there were no prospects for "oil fever". In November 1861 H. Janes made another attempt to implement the pipeline transport project. During the meeting of the Tarr Farm production companies (the river Oil Creek valley), the consent from one of the owners was obtained, but the project was never implemented because of the great number of protests from alternative oil transporters.

The first permission to lay a pipeline in Pennsylvania was received by the Oil Creek Transport Company in 1862, but the pipeline had been never built over the numerous various issues, including deliberate damages caused to the pipeline structure by owners of water and animal-drawn transport.

The first oil pipeline was built only in 1865. In the course of its construction guards were placed along the entire length to prevent numerous attacks conducted by owners of other transport types [17].

In Russia the first idea of using a pipeline for pumping oil and refined products was developed by D. Mendeleev in 1863. However, only in the fall of 1878 the first Russian commercial 9 km long oil pipeline designed by V. Shukhov started its operation. The pipeline construction process also dissatisfyied the owners of animal-drawn carts who transported oil the traditional way. Such dissatisfaction was expressed in frequent arsons and pipeline damages. Guards were placed along the entire pipeline route to eliminate these problems [18].

The described behavioural model of the owners of alternative transportation modes was triggered by their concern about the loss of demand for their services. These examples demonstrate the need to develop a detailed mutually beneficial programme for reprofiling companies engaged in construction and launching of space transport systems, in order to prevent hindering the process of the GPV establishment that may be conducted from the side of such entities.

For implementation of the SpaceWay subprogramme, the authorities are expected to form a comprehensive programme that includes both plans on fi ld-specifi companies transformation and a detailed description of possible results after the project implementation.

25.4 Economic and Socio-Political Effectiveness of the SpaceWay Subprogramme

A. Ways of Economic Benefits Deriving

Space for the industry is an almost inexhaustible source of energy, raw materials, spatial resources and fundamentally new technological opportunities.

The GPV establishment on the territory of the participating countries will open up the following promising activities which entail sighnificant economic benefit

1) creation and operation of a next-generation infrastructure: highly efficient and environmentally friendly transport capable to deliver about 10 mln tons of cargo and 10 mln passengers to the orbit per flight. The economic effec of geocosmic transportation via the GPV (subject on savings of 10 mln USD per the delivery of each ton of cargo in comparison with rockets employment and planned volume of transportation to orbit during the first operation year of 100 mln tons), will be about 1,000 tln USD (11.5 tln USD according to the current money value) [12];
2) establishment of industrial facilities (mechanical engineering, metallurgy, chemistry, electronics, pharmaceuticals, biomedicine, etc.), scientifi laboratories, solar and other power plants in the Earth orbit. Low gravity provides favourable conditions to produce artifi ial organs and telecommunications equipment, weightlessness environment and low gravity make it possible to produce unique alloys, ultra-pure and super-strong substances and materials, which will give an economic effect of more than 20 tln USD per year. The following products have potential to be manufactured in the orbit:

- ferrous and non-ferrous metallurgy products;
- high-strength composites;
- biologics, medicines;
- high-precision parts, components, and all kinds of equipment;
- robotics, electronics;
- communication systems, including mobile phones;
- various types of computer equipment and much more;

3) mining of iron-nickel ore, platinum, cobalt, and other minerals on asteroids with their subsequent delivery to the Earth orbit. A relatively small metal asteroid (1.5 km in diameter) may contain various metals, including precious ones, amounting to 20 tln USD. One small asteroid (1 km in diameter) may contain up to 2 bln tons of iron-nickel ore, that is equals to about 112 bln USD in money terms [12];
4) using the GPV as a giant linear kinetic power plant: exceedance of the reverse cargo flow over the direct one will allow converting potential and kinetic energy of the space cargo into electricity. Net energy profit will be about 200 USD per ton of excess cargo, i.e., 400 mln tons of excess cargo per year will ensure a net energy profit amounting to 80 bln USD [12]

5) establishment of a base on the Earth orbit and in outer space for scientific experiments with hazardous substances, biological agents or physical phenomena, as well as for disposal of stockpiled chemical weapons and nuclear waste that will allow to reduce the costs for construction of expensive and hazardous waste burial sites and waste disposal plants on the Earth, as well as to remove the costs of storing stocks and wastes, the expenses on damage levelling and rectification of the accidents consequences in the amount of 50 bln USD annually;
6) constraction and employment of the TransNet transportation and infrastructure complex with a length of more than 40,000 km (high-speed, urban, and hyperspeed routes), which is combined with the GPV launching overpass [12]. It will enable receiving an annual economic effect from passenger and cargo transportation in amount of more than 150 bln USD which will be increasing continuously taking into account growth of demand for space products and efficientl functioning of logistics system;
7) construction of a linear pedestrian cities of cluster type along the GPV launching overpass. This will enable the population relocation (about 150 mln people) to an eco-friendly zone of increased safety and improved the quality of life, ensure resource savings, as well as increase investment and tourist attractiveness of the territory and its prestige. The annual economic effect of such cities may reach the amount of more than 100 bln USD;
8) implementation of a global innovation project can incentivise lots of complementary innovations employment of which will provide extra revenue for the Earth industry. In particular, the following projects should be highly profitable:

- production of biohumus and innovative lignite-based energetics related to it;
- water and air treatment technologies;
- energetics based on space hydrogen;
- “patching” of ozone holes with oxygen and ozone from space via water decomposition, and environmentally friendly management of the weather and climate on the planet through such holes;
- other activities.

Even a small percentage of high-tech components that may be embedded in the GPV will provide receiving about 100 bln USD of profit annuall .

The obtained economic effe t is slated to be distributed among the participating countries with respect to the size of their contributions to the GPV establishment and area within their territory that will be occupied by the geocosmic transport infrastructure.

Along with all the above-mentioned aspects, each participating country can individually open up new opportunities for development and economic growth due to the GPV establishment and operation on their territory. Some potential business lines are listed below, as well as the expected economic impact of their developing. The effect is calculated using the following method: it is estimated as the differenc between “without project” and “with project” states.

Brazil, Indonesia, Gabon. Logistics hubs can be established in Brazil, Gabon, and Indonesia in order to organise efficien transportation of space products. Convenient location toward estimated delivery regions, as well as availability of developed support infrastructure and qualified personnel (due to high degree of development of these countries) provide the possibility to arrange logistic centres in these countries to cover the following areas: from Brazil to North and South America, from Gabon to Europe and the CIS countries, from Indonesia to Asian countries. A highly developed transport and infrastructure complex will provide efficien multimodal transportation. The annual economic effect from each logistics centre will amount to more than 30 bln USD.

Maldives. The GPV establishment on the territory of this country will significantly increase its transport accessibility and attract more tourists. It is possible to meet the increased demand by bringing 992 uninhabited islands into tourism activities (currently there are only 200 inhabited Islands among 1,192 available ones). Taking into account the actual cash flow from international tourism and sales of travel goods in 2018 which amounts to more than 6 bln USD with reference to 80 commercially active islands the annual economic effect due to involvement of extra territories and arrangement of tourist services there with estimated profitability of 30 % will total more than 20 bln USD per year [19, 20].

Colombia. The necessity to carry out many research and development activities for the SpaceWay subprogramme implementation requires for establishment of a large scientific and technical centre. The current level of research activity indicates the potential interest of local highly qualified specialists in the project, as well as it is also planned to attract experts in the main areas of natural, technical, and human sciences from around the world. It is planned that the centre will become a base for scientific and technical activities, both for the GPV establishment and other innovative developments. The effect obtained from commercialization of other scientific developments can reach more than 100 bln USD annually [1].

Ecuador. A large number of metalworking enterprises and cement factories in the country can be employed to product some construction materials and structures, which are necessary for the Industrial Space Necklace “Orbit” in near space. It will provide an economic effect of about 5 bln USD annuall .

The Democratic Republic of the Congo, Republic of the Congo, Uganda, Kenya, Somalia. Application of soil remediation technology with the use of relict humus derived from brown coal will increase crop yields in these countries. The TransNet network will provide lower cost delivery of both hummus in amount necessary for agricultural soil restoration and harvested eco-friendly products to the world market. The annual economic effect for these countries will be about 20 bln USD.

Sao Tome and Principe, Kiribati. Advance in transport accessibility will increase the tourists infl w by at least 30 %. Subject on data about incomes from tourism and travel goods sale, an additional annual economic effect may amount to 10 mln USD and 1 mln USD, respectively [22–25].

B. Assessment of the Interaction Model Between Society and Authorities

A necessary term for the GPV establishment and its passing through the launching overpass on the territory of equatorial countries is the consent of authorities and society to implement this subprogramme.

The priority goal of any state policy is to ensure a high quality of life for its citizens. Great benefits that can be derived from implementation of the SpaceWay subprogramme may significantly affect the level of citizens well-being, and this implies an absolute interest of authorities in the project implementation.

The potential socio-political effe tiveness of the SpaceWay subprogramme means joint achievement of strategic goals by the authorities and society. Effectiveness is assessed as the possibility for the authorities to achieve the target result in favour of the citizens.

Desicion making process on implementation or refusal to implement the SpaceWay subprogramme is determined by the state current political regime, which reflects degree of the society influence on the state management processe

In countries with an authoritarian political regime (Uganda, Kenya, Somalia, Maldives) the powers of the legislative and executive authorities allow to make a decision on the GPV construction within the state territory without consent of its society.

The majority of equatorial countries have a democratic regime that requires for consent of its population to implement the subprogramme.

To achieve social solidarity regarding the GPV establishment, the authorities should consider a comprehensive programme for assessing possibilities of life quality improving through obtaining benefits from new activities. The state policy should contain support measures for persons planning to assist in the project implementation (such measures as training/retraining, high-quality medical care, benefi s for real estate purchasing, etc.), as well as provide mutually beneficial programmes for reprofiling companies and involving citizens engaged in the creation of space transport systems and hazardous industries in new activities.

Agreement/disagreement of the citizens on the SpaceWay subprogramme determines the further model of interaction between society and authorities in the course of the GPV establishment [26]. Possible models of this interaction are shown in Table 2.

The optimal model for the SpaceWay subprogramme successful implementation is cooperation between society and authorities that is expressed in participation of citizens in the GPV establishment process. The socio-political effectiveness of the subprogramme can only be ensured if the parties cooperate.

Citizens exercise their right to participate and influence on the country development through expressing their agreement/disagreement on the GPV establishment, that will increase social and political satisfaction in society.

Table 2 – Possible models of interaction between society and authorities in the course of the GPV establishment

Rate of society agreement	Model of interaction between society and authorities	Model characteristics
Agreement	Cooperation	Participation of citizens in of the GPV establishment
Passive agreement	Lack of cooperation	The project is ignored by the society
Disagreement	Confrontation	Hindering the process of the GPV establishment

25.5 Conclusions and Lines for Further Research

As it was shown above, the GPV establishment is only possible if society and authority cooperate. The optimal model of interaction expressed in participation of citizens in the process of the GPV establishment will open up a lot of new opportunities for the project stakeholders in obtaining economic benefits

To achieve public agreement on the GPV establishment on the territory of the country, the authorities must convince citizens in the project eff ctiveness, as well as prevent possible resistance from the industry competitors by developing a mutually beneficial programme for their companies transformation

The economic efficienc of the programme is ensured by several new activities in transport, energy, mining, pharmaceutical, chemical, and other industries that will allow get extra benefits from them

The socio-political effectivenes of the SpaceWay subprogramme is expressed in increasing social cohesion and trust in the government through joint implementation of the project ensuring the life quality improvement.

The main task of further research is to identify potential sources for the project financing

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26

Localisation of Industrial Facilities in the Circular Equatorial Near-Earth Orbit

26.1 Introduction

Modern scientific research in the field of harnessing potential of the terrestrial resources, higher consumption of natural and food resources, formation of new consumer behaviour models, new challenges faced by the humanity in the 21st century inevitably leads to issues relating to sustainable further development of economy and industry, as a whole [1].

It is obvious that territories capable of meeting the criteria of sustainable development [2], strengthening "the immune system of the planet" [3], will be occupied by industrial enterprises utilising new technologies. Therewith, alternative options of industrial development are developed.

Various approaches to solve the given problems are being examined today. A number of researchers [4, 5] noticed that globalization tendencies in the contemporary business environment have taken a world-wide scale and require more intensive development solutions. The project of creating an industrial cluster in the Industrial Space Necklace "Orbit" (ISN "Orbit") can become one of the feasible options [3].

Considering that establishment of facilities in the circular equatorial near-Earth orbit will require for taking long-term strategic decisions, the importance and significance of which can hardly be overestimated and their innovativeness level is rather high, the authors have developed a method to evaluate economic optimality and rationality of the business system. This methodological approach has become one of the key tools for taking well-evaluated strategic decisions.

The main task is to determine the most rational selection of business elements for formation of the optimal ISN "Orbit" system in order to ensure technological and economic advantages through transfer of technological processes to outer space. For example, the benefits can be seen in acquiring unique limitless industrial resources such as zero gravity, deep vacuum, mineral and energy resources, and nearly unlimited space.

The method is based on the multipliers concept which is widely implemented in the existing strategic management and includes their weighted estimation [6]. The proposed model consists of those multipliers which characterise both economic activity and physical processes. Such multipliers are combined with weighted average estimation of indexes regarding location of production facilities on ISN "Orbit".

In the course of the method development additional attention was paid to analysis of the theories existing in modern science relating to space industrialization as well as up-to-date methods of data acquisition, processing, and analysis that are used in the proposed model.

Therewith, the authors performed evaluation of the model based on data of 12 companies taking into account specifics of their activities, profile, and peculiarities, which makes it possible to confid ntly confir fl xibility of the developed model, in particular, and the methodological approach, as a whole. However, in the authors' opinion, calculations, and conclusions concerning the ISN "Orbit" project are of the greatest scientific and practical interest

26.2 Literature Review

Currently, scientific community is interested in investigation of space industrialization prospects and opportunities. A large number of publications devoted to this research topic came out in the 1980s–1990s, however, this topic is being even more relevant nowadays. Scientists and practitioners describe space as a place of limitless resources and energy. For example, M. Sonter examined peculiarities of the projects in mining on asteroids and also proposed a method of economic estimation and calculation of net present value (NPV) [7]. Other scientists have examined the projects of orbital space employment for companies located on Earth. M. Jussawalla in his publication examined economic relations regarding creation of satellite communications in the orbit [8]. Russian scientists also paid close attention to the issue of space industrialization. For instance, Doctor of Technical Sciences V. Klyushnikov stated in his work that the final aim of the space industrialization is transfer of aerospace industry and other industries into outer space [9].

Since space industrialization is firstly connected to the level of the terrestrial industry development, it becomes obvious that investigation of the Industry 4.0 prospects [10] in general and advanced technologies, like 3D Printing [11], transportation technologies [3], and digital communication technologies [8] have special importance. According to assessments of G. Schuh, R. Anderl, J. Gausemeier, M. Hompel,

W. Wahlster, and other modern researchers, the potential of Industry 4.0 is estimated at about 100–150 bln EUR [10].

All these aspects made it possible to distinguish companies that should be considered in the course of taking managerial decisions based on serious evaluation processes.

The key factor for companies in taking such decisions is used production technologies and need in acquiring additional limitless resources. Scientists and practitioners have identified zero gravity, deep vacuum, mineral and energy resources, and infin te space as beneficial cosmic resources [12]. An example of such innovative technologies is production of foam steel and composite materials that stratify in liquid state on Earth because of gravity [3].

Additionally, production processes available in outer space include the following: production of silicon wafers, monocrystals growing, production of microchips, semiconductors [13], and microprocessors, as well as implementation of biotechnologies. Among other things, in this paper the authors have considered such manufacturers as Rubicon Technology, Inc. [14], TSMC [15], AMD [16], and Bayer Group [17]. All of them have the following common features – unique requirements for the manufacture sites and operation processes needed to be run with close to zero gravity or ideal vacuum and ideal environmental cleanliness, as well as tightness of the surrounding space and striving to minimize CO_2 emissions in the atmosphere.

The second aspect in selection of the analysed companies is their fixatio on the Fourth Industrial Revolution and development of technologies and innovations that increase economic efficienc of finished goods with limited human participation. According to the data of McKinsey & Company consulting agency, there are landmark corporations that set the tone to Industry 4.0 [18]. In this aspect the authors examined 16 companies [18]. The companies of this sector are represented by the such manufacturers as BMW [19], Johnson & Johnson [20], Procter & Gamble [21], and Bosch Automotive [22].

Another aspect in selection of the analysed companies is their aiming for global leadership on the market and generally high level of capitalization, that is illustrative of high trust of investors who own the company shares. According to the data from Fortune Global 500 magazine, for 2017 the total capitalization of the S&P 500 list corporations reached its maximum value and exceeded 20 tln USD [23]. Such famous companies as Walmart Inc. [24], General Motors [25], BP Group [26], and Samsung Electronics Co., Ltd. [27] meet this criterion.

At the stage of data collection in relation to the three above-mentioned criteria for formation of companies groups, only those companies were considered which disclose information about their financial state and annually publish data on their corporate websites. The accounting documents which are publicly accessible were used during the analysis [14–22] because of their availability at the time when the method and model were tested.

Subject on the conducted studies the authors have confir ed the above-mentioned tendencies of modern industrial development, formulated empiric proof of presence of such representative companies which are potentially ready to make progress

in the presented directions, that increases relevance and feasibility of the project on the industrial clusters creating on ISN “Orbit”.

As a result of the conducted research the authors can conclude that space industrialization provides great prospects as well as the high level of Industry 4.0 implementation and proposed location site for industrialization facilities on the ISN “Orbit” are two equidirectional backgrounds for sustainable development of our technocratic civilization [3].

26.3 Method Description

In the course of conceptual investigation of information about technological spheres the authors proposed eight indexes which are used for ranging of three companies groups regarding rationality and optimality of their placement in ISN “Orbit”. Both widely used approach to economic estimation [28] and physical aspects of the companies activities influencing the economic results reflected in accounting documents are considered during development of the indexes. In addition, comprehensive estimation of activities of the selected companies, as well as availability of information contained in public accounting documents that is needed for calculation of the multipliers were considered during the analysis. Description of the developed indexes is given in Table 1.

Table 1 – Description of the indexes with values correlation

Estimation of the company regarding its localisation in ISN “Orbit”	Estimation formula	Correlation	
		Parameters	Factor*
1	2	3	4
The 1st group of indexes			
Estimate of industrial potential	EBITDA / (CAPEX – Buildings & Land and Land improvements)	Between EBITDA and CAPEX	1
Estimate of technological potential	Revenue / (Inventories – Finished goods)	Between Revenue and Inventories	0.99
Estimate of operational potential	Gross profit (General and administrative + Sales and marketing expenses)	Between Gross profit an Sales and marketing	0.98
Estimate of economic potential	EVA / Total assets	Between EBIT and EVA	0.98
The 2nd group of indexes			
Estimate of labor contribution	Work active / Personnel	Between personnel number and Work active	0.31

The end of Table 1

1	2	3	4
Estimate of transport expenses during product production	Gross profit / Transportation cost from General Planetary Vehicle (GPV)	Between expected expenses for transportation from ISN "Orbit" and Gross profi	0.74
Estimate of market potential	Value market / Revenue	Between the annual market volume and Revenue	0.71
Estimate of energy consumption	Power consumption (MWh) / Revenue	Between power consumption for production and Revenue	0.4

* Correlation factor derived from the evaluation of the data of the 12 selected companies.

The division of indexes into two groups is performed in accordance with the approach to estimation and source of the used information. Therewith, the data obtained only from the company accounting documents was used for the 1st group of indexes. This is evidenced through a high level of the correlation factors. Conversely, the company data and information collected from other sources, for example, information about market size and power consumption, were considered for estimates of the 2nd group of indexes.

The correlation factor [29] was calculated through comparing the parameters specified in the table with one another according to the general list of the analysed companies. For example, the correlation factor of 1 in the industrial potential estimate (Table 1) shows that correlation between EBITDA and CAPEX indexes is positive for all 12 companies.

There is a detailed description of backgrounds for the multipliers set in Table 2 in order to estimate prospects of the companies placing in ISN "Orbit".

Table 2 – Description of indexes and specification of main sourc s of information for their estimation [28]

Estimation formula	Description of the proposed relationship	Pointing of the source from the company's report	Short working name of the index
1	2	3	4
The 1st group of indexes			
EBITDA / (CAPEX – – Buildings & Land and Land improvements)	A company invests to provide its development. The investment volume designates CAPEX level. The report on Cash flows contains informatio about investment in assets (Purchases of assets). After investment in assets and investment in buildings, structures, and land that is left investment in equipment and other assets. The higher EBITDA and the less the required investment in equipment are, the larger multiplier and the higher the reward of investment in technological process will be. Lower dependence on investment in land and buildings enables considering the possibility of location in ISN "Orbit"	Consolidated statements of operations Consolidated statements of cash flow Property and equipment appendix	Industrial

The continue of Table 2

1	2	3	4
Revenue / (Inventories – – Finished goods)	The inventories scope corresponds to the required volume of revenue. Therewith the companies specify the inventories scope in their reports according to the technological process stages. The higher the revenue and the lower the scope of inventories needed for furnished products output are, the shorter the production cycle is. If the inventories scope is lower and the revenue is higher, the supply chain and dependence on suppliers are lower. The lower the dependence on suppliers is, the greater possibility to locate technological process in the ISN "Orbit" will be	Consolidated statements of operations Consolidated balance sheets Inventories appendix	Technolog-ical
Gross profit (General and adminis-trative + + Sales and marketing expenses)	Gross profit includes the company s profi from production and sales of goods. If performance of these operations requires less general and administrative expenses, marketing and sales expenses, it means that the company's processes are conducted in an effective wa . As a result, the potential of such production transfer to the ISN "Orbit" is higher than that of companies having bloated administrative and general expenses and falling short of the required Gross Profi level	Consolidated statements of operations	Operational
EVA / Total assets	EVA index represents the company's profi from current operations excluding taxes with deduction of payment for all capital invested in the company. The ratio of this index to the total assets value brought to the common denominator of currency (USD) demonstrates a great return from invested capital with respect to all assets. And if this return is higher, it means that the company has a business model that enables it to carry out economic activities in a more effective way and, as a result as well as the possibility to locate the technological process in ISN "Orbit" is higher	Consolidated statements of operations WACC level Consolidated balance sheets	Economic
The 2nd group of indexes			
Work active / Personnel	The term of Work active, according to the authors of the present research, includes all company's non-monetary assets and inventories enabling the company to carry out its operations. Hereby, it includes everything that characterises the company's assets directly participating in production. The lower the personnel number required for Work active support is, the greater possibility to locate the process in ISN "Orbit" is	Consolidated balance sheets Data on the personnel number from the company's report	Personnel

The end of Table 2

1	2	3	4
Gross profit Transportation cost from GPV	The following approach was chosen to estimate the company's cargo transportation costs. The weight of produced goods was determined. The author in publication [3] specifie the transportation cost of 1 kg of cargo (less than 10 USD). A simulated situation was considered when the company places its production in full in ISN "Orbit" and transports its products to Earth. The data were compared with the company's gross profit t examine the possibility of covering transportation costs. Respectively, the lower the costs of cargo transportation from ISN "Orbit" in relation to gross profit are, the greate the possibility to locate the process in ISN "Orbit" will be	Consolidated statements of operations Data on production volume in physical terms Average weight of one production unit	Transport
Value market / Revenue	The ratio of the total market size in monetary terms according to the experts estimates and the company's profit share in the total market size demonstrate the company's market potential. The higher the market potential is, the more attractive the decision of production location in ISN "Orbit" for the company will be. The estimate of the world market is given	Consolidated statements of operations Data on the market size in monetary terms according to the experts	Market
Power consumption (MWh) / Revenue	The ratio of power consumption in the course of the company's operation to the total profi volume demonstrates the company's dependence on power consumption. The higher this consumption per production unit is, the company will be interested to a greater extend in usage of energy alternative sources and solar power as a part of an alternative sources	Consolidated statements of operations Data on the power consumption rate from the company's report	Energy

26.4 Results of Analysis

Table 2 provides results of estimation of 12 companies based on the proposed eight indexes. The estimation results are summarised in Tables 3–5.

Table 3 shows that the greatest prospects of technological process location in near-Earth space refer to TSMC and AMD companies, among other things, based on the values of indexes 2, 3, 6 (the predominant indexes are highlighted in green). The given companies are among the world leaders in the field of production of semiconductor systems and microprocessors. Although Rubicon Technology, Inc. is a leading producer of monocrystals, the obtained values of the indexes (in particular, indexes 3, 6, 8) at present provide evidence of a lower prospects for technological process relocation to the near-Earth orbit.

Table 3 – Values of indexes by four companies for 2018 with orientation at space resources

	Rubicon Technology, Inc.	TSMC	AMD	Bayer Group
The 1st group of indexes				
Index 1 – Industrial	0.675*x*	2.58*x*	4.114*x*	7.12*x*
Index 2 – Technological	2.166*x*	11.224*x*	13.268*x*	3.301*x*
Index 3 – Operational	0.006*x*	18.964*x*	4.354*x*	1.437*x*
Index 4 – Economic	0.016*x*	0.152*x*	0.095*x*	0.022*x*
The 2nd group of indexes				
Index 5 – Personnel	0.097*x*	1.166*x*	0.184*x*	1.069*x*
Index 6 – Transport	0.004*x*	241.341*x*	188.958*x*	109.736*x*
Index 7 – Market	0.03*x*	0.07*x*	0.15*x*	0.04*x*
Index 8 – Energy	0.04*x*	38.14*x*	53.51*x*	4.94*x*

Table 4 – Values of indexes by four companies for 2018 with orientation at Industry 4.0

	BMW	Johnson & Johnson	Procter & Gamble	Bosch Automotive
The 1st group of indexes				
Index 1 – Industrial	1.596*x*	12.824*x*	5.96*x*	3.015*x*
Index 2 – Technological	21.177*x*	25.312*x*	34.754*x*	12.884*x*
Index 3 – Operational	2.109*x*	2.417*x*	1.702*x*	1.749*x*
Index 4 – Economic	0.003*x*	0.127*x*	0.082*x*	0.004*x*
The 2nd group of indexes				
Index 5 – Personnel	0.808*x*	0.862*x*	1.05*x*	0.157*x*
Index 6 – Transport	0.496*x*	54.599*x*	0.116*x*	4.322*x*
Index 7 – Market	0.12*x*	0.05*x*	0.15*x*	0.1*x*
Index 8 – Energy	15.76*x*	23.48*x*	3.33*x*	10.86*x*

Table 4 shows that distribution of the obtained results is less uniform. This can speak of potential location prospects for each of the four given companies in the circular equatorial near-Earth orbit, however, not for the entire business operation, but for a number of technological processes. For example, for Bosch Automotive company the prospect of location in the orbit concerning access to the energy resources (index 8) and the level of development of technological processes (index 2) is high. For BMW company such an operation can be 3D Printing with higher quality in zero gravity and vacuum which can be used for critical car parts production and assembly of the units (index 2) and provision of the need in energy resources to increase energy efficiency of process operations (ind 8).

Table 5 – Values of indexes by four companies for 2018 with orientation at leadership in the fiel

	Walmart Inc.	General Motors	BP Group	Samsung Electronics Co., Ltd.
The 1st group of indexes				
Index 1 – Industrial	10.356*x*	2.693*x*	10.852*x*	3.433*x*
Index 2 – Technological	11.428*x*	34.405*x*	21.605*x*	12.099*x*
Index 3 – Operational	1.192*x*	1.203*x*	1.373*x*	2.122*x*
Index 4 – Economic	0.071*x*	0.016*x*	0.036*x*	0.117*x*
The 2nd group of indexes				
Index 5 – Personnel	0.082*x*	0.899*x*	3.357*x*	0.986*x*
Index 6 – Transport	0.196*x*	0.258*x*	0.634*x*	1.618*x*
Index 7 – Market	0.04*x*	0.21*x*	0.01*x*	0.19*x*
Index 8 – Energy	35.74*x*	16.34*x*	0.78*x*	5.76*x*

Table 5 shows that although Walmart Inc. due to its business specifi s suits for location of its operational activities in near space in one of ISN technological clusters to the less extent (indexes 2, 3, 6) than, for example, Bayer Group (Table 3), however, high dependence on power consumption (index 8) for sales of products makes it possible to conclude about the possibility of offering additional capacities of power generation in the space as a kind of service. Table 5 also shows that technologic procedures of Samsung Electronics Co., Ltd. can be analysed regarding their transfer to the near-Earth orbit (index 2) in case of improvement of such indexes as the ratio of EBITDA to CAPEX with correction for investment in buildings and structures (index 1).

In the course of the method development, weighting factors were assigned to each index (Table 6). Weighting factors were stated based on their impact on the final result and the level of correlation between the governing parameters.

Using the average weighted estimate formula, it was possible to calculate the sum of indexes taking into account the weighting factors:

$$\sum = K_1 \times M_1 + K_2 \times M_2 + \ldots K_n \times M_n, \tag{1}$$

where K_1 – weighting factor value;
M_1 – multiplier value.

Table 6 – Weighting factors used in the estimation model

Field of estimation in the company regarding location in ISN "Orbit"	Estimation formula	Correlation		Weighting factors
		Parameters	Factor*	
The 1st group of indexes				
Industrial potential estimate	EBITDA / (CAPEX – Buildings & Land and land improvements)	Between EBITDA and CAPEX	1	0.2
Technological potential estimate	Revenue / (Inventories – Finished goods)	Between Revenue and Inventories	0.99	0.1
Operational potential estimate	Gross profit / (General and administrative + + Sales and marketing expenses)	Between Gross profit and Sales and marketing expenses	0.98	0.2
Economic potential estimate	EVA / Total assets	Between EBIT and EVA	0.98	0.1
The 2nd group of indexes				
Personnel labor contribution estimate	Work active / Personnel	Between the personnel number and Work active	0.31	0.15
Estimate of transport costs in the course of goods production	Gross profit / Transportation cost from GPV	Between the expected costs of transportation from ISN "Orbit" and Gross profi	0.74	0.05
Market potential estimate	Value market / Revenue	Between the annual market volume and Revenue	0.71	0.1
Required power estimate	Power consumption (MWh) / Revenue	Between power consumption for production of goods and revenue	0.4	0.1

* Correlation factor derived from the evaluation of the data of the 12 selected companies.

The higher the final value is, the higher the probability of location of the company's industrial technological sphere in ISN "Orbit" will be. The sum of final values for the twelve companies is given in Table 7.

The final estimate value demonstrates the probability of taking decisions on relocation of the manufacturing facilities to ISN "Orbit". The firs half of the list includes the companies that are prominent representatives of technological specifics with the need in additional resources: zero gravity, vacuum, and energy. In particular, they are TSMC, AMD companies, as well as corporations with orientation at Industry 4.0 – Johnson & Johnson and Bayer Group.

Table 7 – Values of indexes by 12 companies for 2018 regarding weighting factors

Company's name	The 1st group of indexes				The 2nd group of indexes				
	Index 1 – Industrial	Index 2 – Techno-logical	Index 3 – Operational	Index 4 – Economic	Index 5 – Personnel	Index 6 – Transport	Index 7 – Market	Index 8 – Energy	Final value
TSMC	2.58x	11.224x	18.964x	0.152x	1.166x	241.341x	0.069x	38.142x	21.509x
AMD	4.114x	13.268x	4.354x	0.095x	0.184x	188.958x	0.146x	53.512x	17.871x
Johnson & Johnson	12.824x	25.312x	2.417x	0.127x	0.862x	54.599x	0.053x	23.482x	10.805x
Bayer Group	7.12x	3.301x	1.437x	0.022x	1.069x	109.736x	0.042x	4.942x	8.189x
Walmart Inc.	10.356x	11.428x	1.192x	0.071x	0.082x	0.196x	0.035x	35.739x	7.059x
General Motors	2.693x	34.405x	1.203x	0.016x	0.899x	0.258x	0.211x	16.339x	6.024x
Procter & Gamble	5.96x	34.754x	1.702x	0.082x	1.05x	0.116x	0.15x	3.328x	5.527x
BP Group	10.852x	21.605x	1.373x	0.036x	3.357x	0.634x	0.01x	0.781x	5.224x
BMW	1.596x	21.177x	2.109x	0.003x	0.808x	0.496x	0.121x	15.761x	4.593x
Bosch Automotive	3.015x	12.884x	1.749x	0.004x	0.157x	4.322x	0.1x	10.864x	3.578x
Samsung Electronics Co., Ltd.	3.433x	12.099x	2.122x	0.117x	0.986x	1.618x	0.19x	5.755x	3.156x
Rubicon Technology, Inc.	0.675x	2.166x	0.006x	0.016x	0.097x	0.004x	0.034x	0.043x	0.377x

26.5 Conclusions and Future Work

Therewith, the proposed method is intended to assist companies in taking optimal decisions on determination of strategy regarding relocation of their manufacturing facilities to ISN “Orbit”. Taking into account economic factors in combination with the current level of technological development and technical advantages obtained from production location in space, the proposed method allows to minimize risks and specify the optimal set of elements and links of the business model under development.

Given the fact that when forming of a long-term development strategy, in the nearest future global corporations will pay more attention to issues of possible localisation of their technical facilities in the near-Earth orbit and consider the probability of locating industrial facilities close to the limitless space resources, high practical significance of using the proposed method of estimating the optimality of the business system under development becomes evident.

The prospects of research in the given field outline further studies in the following directions:

- analysis of indexes on a higher number of target companies with prospects of their location in ISN “Orbit”, subject on the data not only for 2018, but for a longer period;
- search for new multipliers providing taking decisions on prospects of production relocation to ISN “Orbit” with development of an integral model;
- hypothetical calculation of production location in the low-Earth orbit in ISN “Orbit” industrial cluster with inexpensive geocosmic transportations by the General Planetary Vehicle and delivery of products to certain Earth-based consumers with the use of TransNet transport system [3], including in comparison with production placement on Earth;
- development of a method for testing hypotheses about technologies location in the ISN “Orbit” industrial clusters. The critical parameter for location of industrial productions in the orbit will be the costs of geocosmic transportations along the route “Earth – Orbit – Earth”. For example, at present because of today’s prices for geocosmic transportations – of over a million dollars per ton – only research and development projects financed by state programmes are carried out and space communication satellites operate in the orbit. The cheaper the geocosmic transportations will be (the target is 10,000 USD per ton and lower), the quicker and with the greater scale a safe cosmic industry alternative to the highly polluting terrestrial industry will be created [3].

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27

The Emergence of Industry 4.0 Technologies as Key Driver of Supply Chain Innovation for Geocosmic Systems

27.1 Introduction

Supply chains are becoming progressively transforming in the way of business partnerships and connections, collaborations, promote innovation, making data-driven decisions, and move and real-time track the shipments, which will be the most important part of the industry transformation towards the geocosmic industrialization. A recent global survey by Deloitte [1] indicated that emerging technologies and supply chain innovation are impacting and driving an enormous evolution in the global supply chain. According to A. Lyall, P. Mercier, S. Gstettner [2], it is predicted, a significant disruption in our current way of working by creating self-regulating and smoothly running utilities that manage holistic workflows with little to none human interaction.

Since the mid-1990s management of the supply chain has been recognized as an important profession amongst practitioners [3–5]. The term "supply chain" is defi ed as the end to end process to produce goods and/or provide services to the final customers [6–8]. Therefore, supply chain management is vital to all businesses. Additionally, the supply chain management practices often deal with sustainability, product and service complexity, and performance measurements [9–11].

Digital technologies are one of the main mechanisms for influencing the operational and supply chain modernization and innovation [12]. Supply chain players need to be aware of the availability of new technologies to be able to keep the pace for increasing customer's demand, who requires faster, cheaper, and customised services/products [1, 13]. Any disruption such as economic recessions and epidemics (e.g., COVID-19) can quickly leave behind those companies and individuals, who are not adaptable according to the changes [14]. But on the bright side, it could be an era of arising opportunities to improve the current supply chain, towards changing the ways we are currently manufacturing, moving, and paying for goods and/or services [15]. These transformational technologies could revolutionize the current supply chain to a smarter and better-connected ecosystem resulting in a flex ible working setting and enhancement in data sharing.

This paper discusses the current adoption rates of emerging Industry 4.0 technologies, and analyse the perspective of today's supply chain professionals observing the impact these technologies have on the future of global supply chains, including geocosmic industry transformation, to guide new informative insights from both professionals and academic researchers, pinpoints opportunities and challenges and benefi s future education in this area. This paper is organised in the following sections. Section 27.2 starts with the introduction of Industry 4.0. Section 27.3 provides insights into different available emerging technologies. Finally, the conclusion and managerial implications offer future directions and geocosmic applications of these technolgoies and required evolutions of the supply chains.

27.2 Industry 4.0

Information technology systems have progressed significantly through a revolution (Figure 1) over the last three decades [16]. The implementation of inter-connected networks without direct human intervention within the operations and production environment is called Industry 4.0 [17]. The term Industry 4.0 has been widely described to consider the Fourth Industrial Revolution with the emergence of digital transformation to enable automation and smart factories and manufacturing [18, 19]. It is expected that the Fourth Industrial Revolution carries out a great impact on the supply chain, especially future investment, employment, and trade [20].

Industry 4.0 brought to the manufacturing significant efficien improvements, integrated ecological control systems and reduction of the required workforce.

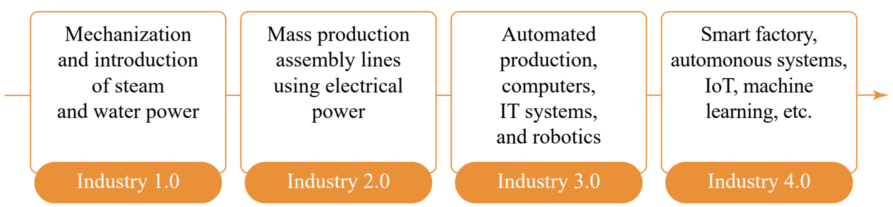

Figure 1 – Four industrial revolutions

As most of the automated systems don't require presence of the human, such technologies can be seen as the most perspective industrial sectors to be moved to the outer space and to be installed in Industrial Space Necklace "Orbit" (ISN "Orbit") [21]. With the improved energy supply, ISN "Orbit" will provide unpresedently welcoming operating environment for the emerging technologies.

27.3 Emerging Technologies

The principle driver for Industry 4.0 is the emergence of key technologies, such as 3D Printing, Advanced Robotics, Artificial Intelligence, Autonomous Vehicles, Big Data Analytics, Drones, the Internet of Things, Blockchain and Virtual/Augmented Reality [22, 23]. The following nine Industry 4.0 technologies were recognized as being the most current significant technologies nowa ays.

3D Printing

Since 2014 the world is experiencing a rapid transformation in manufacturing, especially with the introduction of 3D Printing (3DP), also known as Additive Manufacturing (AM) [3], where the first electric car was printed for the first time and took 44 hours [24]. 3DP has precise control over the shape of the objects by printing the product layer-by-layer using computer-aided design files [25]. The potential impacts of 3DP on the supply chain are customization, customer value proposition, and competitive advantage [26, 27]. Figure 2 illustrates this impact.

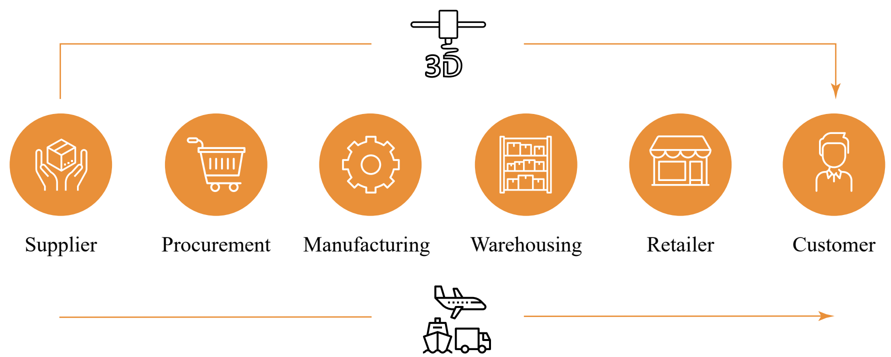

Figure 2 – Impact of 3DP on logistics and supply chain [3]

As a rapid prototyping, 3DP requires significantly precise control over the temperature flow for the filament and instant cooling to maintain high-quality production. ISN "Orbit", as the working environment, provides the best operating

conditions in terms of the temperature control and other environmental parameters for 3DP operations. Furthermore, relatively high exhaust of the chemical fumes can be mitigated or neglected, when such tehcnologies are placed in the outer space [28]. It means that the production rate can be significantly increased.

Internet of Things

The Internet of Things (IoT) is a global structured interconnected object in a network articulated with intelligence, recognizing patterns and sensing technologies [29]. The objects or things can be a range of sensors, actuators, pumps, and washing machines, to weighbridges, water meters, lights, or Radio Frequency Identifier Device (RFID) [30, 31]. The benefits from Io can be identified as

- improvement in the identification of fake/not original products
- real-time monitoring/tracking;
- predictive maintenance;
- accurate data in sales;
- a significant decrease in overproduction/underproduction;
- biometric payments;
- improved competitiveness;
- sustainable developments of IoT-based processes [22].

IoT provides the main connectivity paradigm for ISN "Orbit" as a whole. Devices and industries should be combined in the ISN "Orbit" with IoT network already being established.

Artificial Intelligence

The term Artificial Intelligence (AI) was first introduced by J. McCarthy from Massachusetts Institute of Technology referring to the branch of computer science that attempts to imitate human intelligence [32]. Supply chains have transformed from the vertical "buyer – supplier" structure into multilayer solution connected using sensors and the Internet of Things. This significant change, which formally known as AI, is owing to the advancement of data science and the availability of new computer generations. AI is a collection of methods and technologies using computers for decision making purposes [33, 34]. The main objectives of AI are to understand the problem and by mimicking the human behaviours, creating the related problem-solving knowledge [35]. The McKinsey Global Institution [36] predicted more than 30 % of the occupations in the US will be affected by AI. The key challenge of AI is the high energy consumption of the computational systems. Placement of the cloud services for the land-based systems on the ISN "Orbit" will provide opportunities to manage energy consumption, as ISN "Orbit" power system relies on the solar energy, rather than on the fossil fuel burns, and controls operating temperatures without any use of the water or harmul chemicals. It means that such centres will provide higher computational resources with lower energy consumption, when they are installed on the ISN "Orbit".

Autonomous Vehicles

Autonomous Vehicles are capable of intelligent motion by perceiving their environment and responding to any unexpected situation [37]. The integration of such technology across the global supply chain is seen as a transformation toward digital supply chain [38]. The implementation of Autonomous Vehicles can lower the shipping cost, accidents, liability, fuel costs, and green gas emissions [39].

Big Data Analytics

In 2005 the term Big Data Analytics (BDA) was coined by R. Muogalas and refers to a large set of data that was not possible to process using traditional business intelligence tools [40]. BDA is now considered as a critical procedure for the management of supply chains [41]. Using BDA befits marketing opportunities, predictive analytics, better forecasting, agility, client-based classification [41]. BDA should be placed as the backbone of the ISN "Orbit" control strategies and its manucaturing processes and transportation strategies for the General Planetary Vehicle (GPV). In addition, integration with the Earth-based information networks will boost efficienc of the manufacturing facilities of the ISN "Orbit" [21].

Drones

Unmanned or micro aerial vehicles are named as Drone. This technology was first used for military services as early as World War II [42]. Drones have now emerged into the supply chain as a potential solution to many challenges such as last mile delivery, stock captivating, surveillance, the inspection of vehicles (ships) and infrastructure, traffi congestion, and pollution reduction [43]. Drones can be used as the monitoring system of the GPV related infrastructure and its take off and landing pads.

Blockchain

Blockchain technology has been the biggest innovations of the 21st century, however, it dates back to the early 1990s. It has since become a decentralised system, where every transaction stored securely and permanently across the supply chain [44]. Figure 3 illustrates Blockchain technology timeline.

Blockchain is known as a system with super-low efficiency. For the space industry application Blockchain can be used for the data security and information exchange. Use of the clean energy will significantly reduce ecological footprint of the technology, precise management of the operating conditions of the computational stations in ISN "Orbit" will further increase the popularity and efficienc of this method of communication.

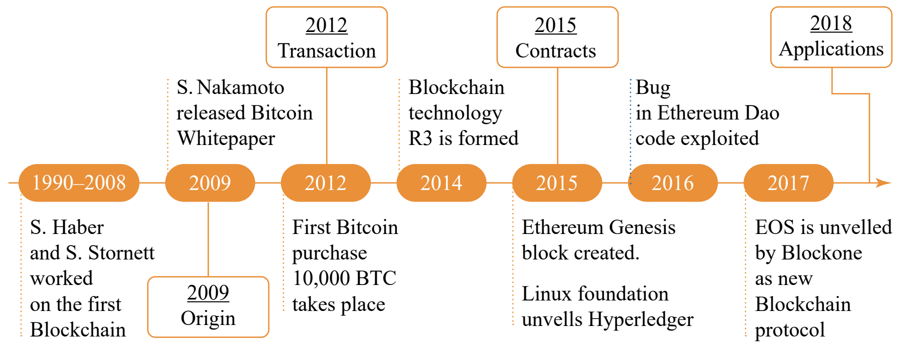

Figure 3 – Blockchain technology timeline

Advanced Robotics

Robotics or Advanced Robotics are electrical pieces of machinery originated to automate processes or supporting humans with the tasks. This emergence of technology is commonplace in manufacturing and warehousing [45]. Robotics have been accepted across the supply chain for their effectiveness in material handling, welding, intensive work repetition, inspection, and cost reduction [46]. To reduce human representation within the harmful manufacturing facilities, most of the industry, added to ISN "Orbit", will be robotics-based, especially for the chemically-intensive and labour-intensive processes, and also in the outer space environment.

Virtual/Augmented Reality

Virtual Reality (VR) allows consumers or operators to relate with sensible electronic simulations of 3D situations using head-mounted goggles and clothing formfi -ting devices [47]. Augmented Reality (AR) defines the capability to assimilate virtual 3D objects into a real environment [48]. VR and AR are recognized for their potential in training or education, product visualisation, work visualisation environments, inventory management [49]. Communication and operations from the Earth-based humanity and ISN "Orbit" manufacturing operations can be efficiently done through VR and AR to boost the manufacturing quality and productivity.

27.4 Conclusions and Future Work

The chapter summarises the current level of adoption of several key emerging Industry 4.0 technologies. There are nine technologies identified as the current technology trends in the supply chain, such as 3D Printing, Advanced Robotics, Artificial Intelligence, Autonomous Vehicles, Big Data Analytics, Drones, the Internet of Things, Blockchain, and Virtual/Augmented Reality.

To extend the existing knowledge in this field, the researchers and practitioners should have a focus on the levels of adoption for each of the technologies in different geographical places, especially narrow down to supply chain perspective by focusing into every supply chain players. These challenges can be further elaborated with the presence of ISN "Orbit" with GPV, as the ideal operating environment from the technical perspectives, for most of the emerging technologies. Communication technologies, followed by AR and VR, will support interactions of humanity with the remotely-located systems.

Lastly, future research requires awareness to decision making methods and impact of Industry 4.0 technologies is important and necessary for the future of supply chains.

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28

Innovation-Driven Business Models and Novel Forms of Business Management

28.1 Innovative Business Models in the EcoSpace Programme Complex

In recent decades, the pace of scientific and technological progress has accelerated significantl . Numerous inventions that until recently were seen just as innovation projects have become the determining standards in the existing industries. Such inventions are, for example, mobile phones, digital photography, electric vehicles, etc.

There are numerous examples of companies which business models are based on the development of new technologies: Apple, Microsoft, Google, Amazon, Uber, Alibaba, etc. According to Forbes 2018 ranking, the Global Top 10 companies measured by market capitalization include seven companies from the new-economy sector. Apple (926.9 bln USD), Amazon (777.8 bln USD), Alphabet (Google) (766.4 bln USD), Microsoft (750.6 bln USD), Facebook (541.5 bln USD), and Alibaba (499.4 bln USD) have been ranked as the top six companies worldwide [1]. The market capitalization of these companies has exceeded the relevant figur of the previously leading industries, such as gas corporations, banks, automobile manufacturers, or retailers, by several times.

Data Science is becoming the centrepiece of the new economy to address the issues of analysing, processing, and digitizing information. Data Science was originally viewed as an academic discipline, however, since the early 2010s, it became an interdisciplinary applied tool. Furthermore, the job of a data scientist is currently considered to be one of the most attractive, highly paid, and promising occupations [2]. Data Science approach is to rely on data-driven decision making processes rather than on intuition- or experience-driven decision making. Data Science is a generic name for the combination of technologies to generate data products, where value is added through data mining procedures that extract useful information intended for human consumption.

In the 1990s, data was not even considered an independent entity. In the 2000s, people started to refer to data as the "new oil". This phrase was first coined by British mathematician C. Hamby in 2006. Numerous experts also repeatedly stated that in the foreseeable future data would gain greater economic significance than raw materials [3]. It is no coincidence that the term "data-driven" has come into general use as an applied approach in various areas, such as economy, programming, journalism, science, etc.

The data-driven approach to the economic sector has been implemented in the Industry 4.0 concept, which was proposed to the German government in 2011. The USA also adopted this strategy in 2014. The Industry 4.0 concept implies flexible control over the production scale and design process, development of Artificial Intelligence, extensive use of Big Data, mainstreaming of the Internet of Things (IoT), Blockchain technology expansion, cloud calculations, robotics, and augmented reality integration.

As a result of the industry's adopting the above principles, business models have also been chainging. Now companies are striving to shift their focus from lean manufacturing to mass customized manufacturing based on agile principles and switch to manufacturing a single product, i.e., lot size one. At the same time, the principle of economy is maintained: robot-driven manufacturing is more energy efficient and results in less waste and less rejected products [4]. As a matter of fact, lot size one can also be embedded into the production methodology of all EcoSpace programme's components. At the same time, the reshoring phenomenon is taking place, i.e., the process of returning innovative industries from the developing countries in Asia back to the developed countries in Europe and America.

In full compliance with the Industry 4.0 concept, the entire complex of the EcoSpace programme, including technological platform Unitsky String Technologies (UST) and the SpaceWay subprogramme, are currently being developed. Solutions, developed within UST and SpaceWay, are aimed to be applicable to the projects of creation, upgrading, and expanding various infrastructure facilities. However, private investors perceive large infrastructure projects as capital intensive ones, having low net present value, and long payback and return-of-investment periods [5]. UST and SpaceWay are unique not only for innovative technological solutions but also because they provide brand new business models for large-scale infrastructure projects.

In particular, the innovative UST is based on hundreds of unique technical, software, and logistics solutions that can offer universal advantages: low capital and operating costs, environmental friendliness, safety, and high effi ency. UST philosophy is based on the following principle: transportation should solve problems rather than create them. Unlike conventional infrastructure projects, the UST concepts are commercially attractive due to their shorter payback period ranging from three to five years. At the same time, the construction cost of the UST transportation system is 2–20 times lower compared to the projects for usual transportation networks [6].

It should be pointed out that development of green technologies is a modern global trend, and the transport industry is no exception. In particular, global sales of electric vehicles are growing exponentially [7]. Significant number of automobile manufacturers has already announced that they will stop developing new models powered by combustion engines over the next 8–10 years. Furthermore, several European countries plan to ban vehicles with such engines during 2025–2030 [8]. Therefore, the environmental friendliness of the UST project is one of the key advantages of this technology, in addition to the materials saving techniques during the overpass construction and energy-efficient operation of the innovative rolling stock

Besides, one of the UST significant competitive advantages is the use of digital products based on Dassault Systèmes' 3DExperience platform. Thanks to the platform, digital mockups can be created for each type of rolling stock or system. This allows to obtain early validation of the requirements, facilitate communication between different departments when amending the design documentation, and conduct virtual tests. Hence, the product development time is significantly improved, and the product cost estimation process can be simplified

Another important component of the UST business model is the extensive use of Big Data and Blockchain technologies. The UST transportation system is controlled by an intelligent automated system. Its key component, a system of sensors, allows performing 24/7 control over cargo and passenger transportations. The system operates on Blockchain protocol to process and store data, including the traffi history, and uses special software with data access restrictions. In order to mitigate the risk associated with fraud, data breaches, and payment errors; the complex solution is based on smart contracts technology.

Due to its innovative business model, the UST share of the global transportation market is expected to reach 50 % by 2100 [6], replicate success of railways in the 19th century and highways a century later. The share of obsolete traditional roads will gradually decrease as new and more efficien solutions will dominate the market.

The non-rocket space industrialization subprogramme called SpaceWay is also based on these approaches and implies creation of the relevant geocosmic transportation system. On the one hand, the SpaceWay concept is intended to transfer the environmentally harmful components of the technosphere into outer space, while the planet biosphere is for life. On the other hand, the innovative business model will turn the SpaceWay subprogramme into one of the most commercially attractive projects in human history. Innovative space industry will open up unseen opportunities in metallurgy, solar power, and mining industries.

The SpaceWay business model is based on cargo and passenger transportation to outer space and return. There are plans to integrate it with the global UST and Umach transportation networks, including intra- and intercontinental transportation systems. The SpaceWay business model provides performance of cargo

and passenger transportation to the Earth low orbit at a price that is 10,000 times lower than the current space industry suggests [9]. This aspect can be considered as the cornerstone of the project commercial attractiveness. One of the other unique features of SpaceWay is the negative cargo and passenger transportation cost that will be provided for the tenth year of its operation. Therefore, SpaceWay is a promising project that will generate a significant profit for its stockho ers.

Thus, these are the key trends of modern industry, and UST and SpaceWay are among them. Both technologies apply innovative business models that can significantly minimize costs without causing any environmental damage. Taking into account all the above, it is obvious that the EcoSpace programme is well positioned to be successfully implemented.

28.2 Blockchain as a Unique Information and Economic Basis for Equatorial Linear City, Its Transport Systems, and General Planetary Vehicle

Rapid development of the cities has raised many challenges, including unbalanced distribution of the resources within the countries. The trend towards urbanization has led to a great number of densely populated metropolises with poor quality of life, contaminated air, and transport collapses. On the other hand, no-man's and undeveloped territories can't attract investments and labor force to such depressed regions.

Herewith, there are several improving trends: many countries and global corporations are taking a course of actions to implement green solutions in their key business processes. A number of countries have developed local programmes to support people who have decided to move from the metropolises to less populous and underdeveloped places and start their businesses there. Lead engineers, architects, and designers are working on the cities of tomorrow. Various ideas within these concepts (for example, use of solar panels as the main power source) are in process yet today.

The linear city concept is considered as one of the most successful projects. This concept is based on a network of high-rise towers spaced apart from each other by 500 m and interconnected by the horizontal string transport systems [9]. According to the project description, all transport, energy, and information communications are located on the second above ground level. It enables to free-up the ground level for pedestrians and environmentally protected sites.

Equatorial Linear City (ELC) is a cluster-based settlement that is stretched along the equator and consists of an extensive network of transport, energy, engineering, and IT infrastructures. The launch of this project is an essential part of the SpaceWay subprogramme because ELC will serve as the basis for the General Planetary Vehicle (GPV). The GPV is the best available and environmentally friendly transport means allowing near space exploration without the use of rockets causing a devastating impact on the environment (the ozone layer is being destroyed, earth, water, and the atmosphere is being polluted by the products of fuel combustion and debris) during their launching [10].

In addition to the architectural look, transport, energy, and communication systems, the coming technological changes will also affect the economy of the cities. The key financial problems of the modern megalopolises include the dominance of the bureaucracy and corruption, development of monopolies suppressing small and medium businesses, lagging decision making processes, and turning potentially profitable projects into long-term construction sites because of the lack of financing

In the context of solving these issues, it can be estimated that many economic processes in the cities of tomorrow should be based on Blockchain technologies. The Internet has changed the world by making the information exchange fast and convenient, it enables connecting people from different countries and even continents via computers and mobile devices. The Internet significantly simplifies a huge number of processes. For example, there no need to call taxi companies to order a taxi at an optimal price or spend a lot of time searching for a particular product and visiting retail stores located in different parts of the city. Paper accounting, which used to cause a lot of problems for companies, especially for the large ones with various branches and subdivisions, has also become a thing of the past.

Blockchain technologies should provide a solution for development of a unified open standard that will combine all financial transactions into a system, reduce time of their execution and the number of intermediaries, as well as facilitate distribution of the funds. Investors of Blockchain technologies will be given an opportunity to expand the range of potentially successful projects that today are difficul to monetize.

Blockchain technologies provide a possibility to combine financial sector, transport systems, telecommunications, and energy industries. It can be used to arrange relations between various stakeholders, including state authorities, investors, entities, suppliers, and consumers. A token is the key element of Blockchain systems.

A token is an accounting unit used to represent digital balance in a particular asset. The tokens are stored in a database, access to which can be obtained only with the use of Blockchain technologies through special applications subject to electronic signature schemes [11]. The tokens simplify mutual settlements and fully automate such processes. Today there are two types of tokens – Utility and Security. Utility tokens are digital coins used to pay for particular services. Utility token can be compared to a single-ride subway ticket because outside of its system (for the ticket it is the subway), it has no value. Security tokens are digital analogues of security papers, that provide the owner with special rights to receive dividends and profi share from the company.

Preparing for an initial public off ring (IPO) is time-consuming and tightly linked to specific countries and stock markets. In addition, companies and purchasers of shares have to use expensive intermediaries, such as auditors and brokers [12]. The IPO method is suitable only for large corporations with multimillion turnover in recent years, for example, corporations owning a network of railways, trains, railway stations, and other assets both inside and outside the country.

At the same time, STO (security token offerings) does not take much time, and it requires a significantly smaller number of intermediaries accompanying the process. This way to attract investments is suitable for promising startups, medium and large businesses for which the IPO is unavailable. Security tokens can be traded on the stock markets around the world under existing legal conditions. In other words, investors from all over the world can finance some local transport project – for example, a linear transport system implemented in the United Arab Emirates.

It should be noted that modern transport networks of different countries are mostly monopolies. The list of companies participating in development of urban systems for passenger and cargo transportation is strictly defined and they operate not subject to the rules of free competition. Because of this, potentially successful projects, including ones using green technologies, remain unimplemented.

Blockchain technologies allow different owners to create new infrastructure objects on the basis of transparent rules of competition and pricing. Moreover, entry of new participants into the on-going project on the transport system development does not require revision of the previous agreements and changes in the mutual settlements.

One of the solutions to moderate relationships between the participants of the infrastructure projects can be presented as follows: with the use of the developed smart contracts system, payments made by the passengers or customers of the transportation system, are automatically distributed among the participants. The amount of charges depends on the carrying capacity or frequency of the resource usage. Such deductions form the income of the companies providing services or participated in construction of infrastructure facilities. Similar economic system can be implemented in ELC.

This approach is suitable for both private and public transport systems: from bicycle sharing and car sharing solutions to the complex ropeway, rail, and string systems, as well as for managing movement of space goods along ELC. The smart contracts will enable transparent, efficient, universal, and monopoly-free way of common use of the transport system by a great number of users – individuals and transport companies, countries and international alliances, etc.

The IoT technology should be also considered [13]. It is a concept that involves interconnection between things and objects into a global network controlled by Artific al Intelligent systems. Their interactions between each other and with the environment are performed by means of built-in sensors, detectors, radars, and lidars. Human participation in this system is minimal [14]. The most notable projects in the IoT area are connected to development of Artificial Intelligence-based autonomous cars. Such projects cause competition among the leading tech-savvy corporations, such as Google, Yandex, Tesla, Waymo, and other automobile and technological giants.

Blockchain provides an opportunity to link tokens with each sensor, radar, or lidar while making the decision making system as transparent as possible [15]. There is an example: a train, controlled by Artificial Intelligence, moves on the track with built-in sensors. It passes through sections belonging to different companies.

Scanning the sensors' authenticators, the system automatically transfers a corresponding number of tokens to the owner of the particular section as a payment for the train passing. Such a system helps to avoid delays and errors and reduces the human factor in the payment processes. Besides, Blockchain is also able to secure information generated by things and objects using cryptographic methods. Thanks to this system, it will be impossible to use specific rails for the UST transport without proper maintenance. In addition, it will be impossible to forge or replace them with a lower-quality analogue.

Blockchain technology can be also used in the energy industry. The technology allows to set up an automated calculation for a number of suppliers and consumers of thermal energy and electric power in order to achieve the fairer tariffs. Payments in this system will be performed according to natural market rules without any artificial regulation [16]. Due to the new system, consumers, generating companies, and grid electricity suppliers will be connected to the unified energy network with the use of only an automatic metering device. Blockchain micropayment technology will provide controlled energy supply using Blockchain contracts. As for the transport system, the balance of supply and demand will be formed in real time, that will ensure competition between prices and operating terms on the basis of the market principles.

Transport operated by a private company is equipped with an individual energy metering device and connected to the power network on a permanent basis. The device provides access to the consumer's smart contract. In order to provide power supply from the network, the vehicle owner needs to maintain a certain token balance. While the vehicle moves, the meter detects the current passing through it, records the time, and calculates the operation cost. The meter registers the electricity consumed in the smart contract and writes off the tokens according to the current tariff.

Blockchain technology will blend seamlessly into the sphere of telecommunication services while simplifying and improving [17]. Blockchain will provide access to the global network and information resources anywhere in the world without entering into a contract with any telecom operator of any country. Such concepts as "guest network" and "roaming" will also become things of the past.

The new principle of communication puts at the forefront the user's mobility [18]. Phones, tablets, laptops, and other gadgets are able to independently detect an available network, determine the best connection options and automatically agree on a mutually acceptable format of payment and cost. In such a system, any device can be either a data-consuming subscriber or a provider of access to the neighboring users while receiving an adequate fee for the provided communication services. In the future, it will be possible to sell telecommunication services with the use of equipment installed on the Industrial Space Necklace "Orbit" (ISN "Orbit").

In conclusion, it should be noted that Blockchain-environment principles with interacting contracts create seamless and flexible links between the receipt of goods and services and associated payments. It allows forming the competitive market that is not possible without such technologies, as well as fair distribution of the income. And all of these advantages are real due to establishment of decentralised autonomous organisations (DAOs) [19]. Unlike ordinary companies that follow a rigid hierarchical structure, DAO consists of equal participants, each of them has unlimited access to information. Herewith, today, this is the most democratic version of the entity arrangement.

All these principles may be used as the basis for economic system of the Equatorial Linear City of tomorrow, and then they are suited for the SpaceWay software system and in all its subprogrammes such as ELC, GPV, and ISN "Orbit".

28.3 New Forms of Management on the Example of Unitsky Space Geocosmic Platform

Nowadays, it can be observed that business is in the period of transformation of business models and forms of management when traditional linear companies are replaced by platform companies that, later on, form ecosystems. Movement of the world towards the platform economy is a long-term trend beyond the IT sector, which in the coming years will change the balance of power on the national and global markets. So, for example, as of March 2020, seven companies of the Global Top 10 in terms of capitalization were platform: Microsoft, Apple, Amazon, Alphabet, Facebook, Alibaba, and Tencent [20].

Each platform has its specifi s attracting various groups of users and creating different combinations of values, but, at the same time, all platform companies have some common (basic) structural components. So, the current purpose is to study the basic operation principles of the platforms and analyse the applicability of these principles to the SpaceWay subprogramme [9].

A. Review of Literature

A number of publications on global trends of McKinsey consulting company have demonstrated that the economy is on the edge of multilateral business models – in particular, platforms [21–23]. The most significant contribution to the formation of the modern general theory of platform operation was made by G. Parker, M. Alstyne, S. Choudary [24], C. Linz, G. Muller-Stewens, A. Zimmermann [25], N. Johnson, and A. Moazed [26]. These papers reveal the basic principles of platforms as innovative business models, present the comparative analysis of traditional linear models and platform models, summarise and analyse the reasons and key needs causing changes of the business model and value proposition in the modern world, provide recommendations on how traditional companies can adapt to the changing market, pay attention to the need for a balance between digital and physical assets, give examples of companies that are carrying out consistent radical changes, success and failure stories of companies in various industries.

Authors G. Parker, M. Alstyne, and S. Choudary named the process of platforms' formation as platform revolution. N. Johnson and A. Moazed highlighted the complexity of the phenomenon of business models' transformation while emphasizing that this phenomenon is comparable in importance for the society with the industrial revolution of the 18^{th}–19^{th} centuries.

In the opinion of authors C. Linz, G. Muller-Stewens, and A. Zimmermann, merging the physical and digital resources of companies transforms many activities and industries, and, therefore, the business strategies of these companies. In addition, G. Parker, M. Alstyne, and S. Choudary concluded that as the result of merging of digital and physical assets the platforms of higher order will be formed, the so-called platforms of platforms.

B. Method Description

General scientific methods have been used during the research: literature review, system analysis, comparison, description, generalization, and systematization of the ideas and their applications.

When a platform business appears in the traditional market, it commonly outperforms other management modes. That is why in recent years increasing number of companies have replaced the linear system with a platform one [24, 25].

Apple has evolved to some degree thanks to combining its products in a cloud environment. The ability to sync data and content on iTunes and iCloud makes having a variety of Apple products particularly valuable and even more useful than the use of different devices – for example, from Sony or other electronics manufactures without the synchronization feature. This leads to a new form of growth when a variety of products are combined and interact using shared data. In the late 2000s, Apple shifted from being a traditional product company to become a business platform. Then Samsung adapted to the new operational principle, and, for example, Nokia failed to do so [26].

Traditional business model is a linear one, wherein a value is created by means of linear processes – chains of value creation (Figure 1). Raw materials, components from suppliers (input) through a series of steps (value creation chain) are transformed into a finished product (output) of greater value than the value of combined input materials. In order to increase profitabilit , traditional linear companies need to reduce the input price, process costs and increase the output value [24, 26].

Figure 1 – Value creation process of a linear company

The scientific literature lacks uniform approaches in platforms definition as well as their classification. As a rule, the platform business model is described as a model of direct interaction and execution of transactions between groups of users through the technological platform. The scheme of the process is shown in Figure 2.

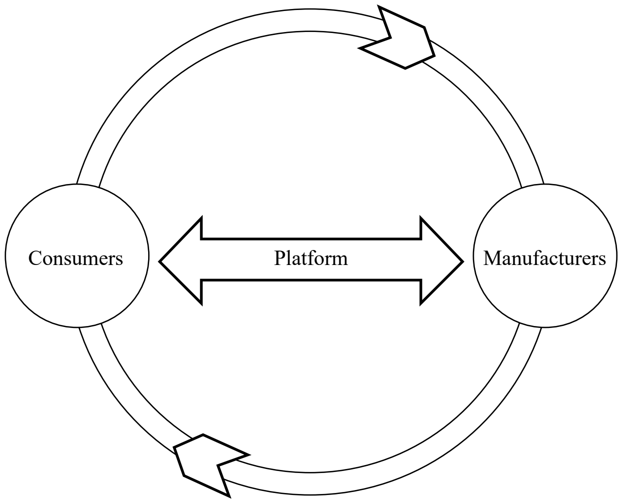

Figure 2 – Value creation process of a platform company

The concept of the platform includes both a technological base itself and an ecosystem. The platform ecosystem, similar to natural ecosystems, is a unity of biotic communities, their habitats, and interrelation systems, where each element performs a specific function within the ecosystem

In the process of interaction with the platform, while using its resources, various groups of users distribute and consume information and create the value. Herewith, the value is created and consumed in different places and different ways thanks to relationships that the platform provides. The value does not move linearly from manufactures to consumers along the supply chain as in a traditional model [24, 26].

The main value of the platform is the community created by the users, so the management focus is shifted from internal to external activity. External resources do not replace the internal resources completely – more often they complement each other. It's as if the company's processes are "flipping over", platform companies count more upon ecosystem management than on product improvements, and focus more on partnership, rather than on control over subordinates; control over relationships becomes more important than control over resources.

Operational management shifts from optimisation of the company's product range and supply chain to the management of the external capital that is not directly managed by the company.

Platform monetization techniques include commission fees, extended access payments, third party payments for access to the community, and payments for extended supervision subscription.

There are a number of legislative issues that are unique regarding platform businesses: access to the platforms, compatibility, fair pricing, data protection and security, tax policy, and labor regulation.

The platform revolution involves using technologies to bring people together and give them tools to create joint value. Platforms are relevant not only for IT companies. Platforms are capable of transforming any industry. The IoT will add a new level of connectivity, scale, and influence to the platforms of the future; on the basis of competent connection of industrial devices, there will be a global platform of platforms while stimulating development and serving the needs of mankind [24].

C. Results and Analysis

The technological basis of the global platform can be found in string transport that meets the described features and trends: availability of physical component (physical assets), optimal combination of physical and digital assets (phygital ones), potential for ecosystem formation, and, most importantly, potential for solving global environmental issues.

In fact, the idea of a global geocosmic platform based on the string transport was conceived by engineer A. Unitsky in the 1980s within the idea of non-rocket space industrialization [9].

The theory of string transport is based on the idea of taking harmful industries outside the biosphere into outer space with the help of the General Planetary Vehicle. The GPV is a geocosmic transport and communication system of multiple uses for non-rocket outer space exploration. Environmentally friendly GPV operation on only the electricity will enable safe outer space industrialization. In the course of works related to the GPV, the idea of creating an ecological ground-based string transport of overpass type – UST – was born. The main principle of string technologies is a practical application of various engineering solutions (structural, technological, operational, digital) that are maximally correct in terms of fundamental laws of physics and resource capacity [9].

Unitsky Space geocosmic platform includes (Figure 3):

- geocosmic transport and infrastructure system (GPV); Equatorial Linear City serving the GPV system, including its take-off and landing overpass; Industrial Space Necklace "Orbit" surrounding the planet in the low circular orbit in the equator plane, which is serviced by the GPV, including its orbital take-off and landing platforms;
- TransNet on the ground transport and communications network, which is based on the UST overpass transportation systems and combined with communication and power lines that interconnect all settlements, countries, and continents on the planet with each other and with the ELC by high-speed and hyper-speed string-based routs;
- users: space industry consumers, i.e., all countries of the world, entire humanity;
- values created on the basis of the platform, including recovery of the planet's biosphere and our technocratic civilization, which is at an impasse, moving to a point

of no return because of the industrial vector of development chosen by our ancient ancestors; transition to a new stage of civilized geocosmic development chosen by us and implemented in the near future by our descendants; a significant improvement in the quality of life for all inhabitants of our common home, Earth, including humans;

- ecosystem: space industrialization means creation of conditions in the orbit for production of various materials, energy, machinery, new information gain, implementation of technological processes, scientific experiments, i.e., an ecosystem that allows other companies, which become partners, to offer the values of their main product through integration with the GPV, which, in its turn, means expansion of functionality, growth of their value and value of the main asset – the GPV.

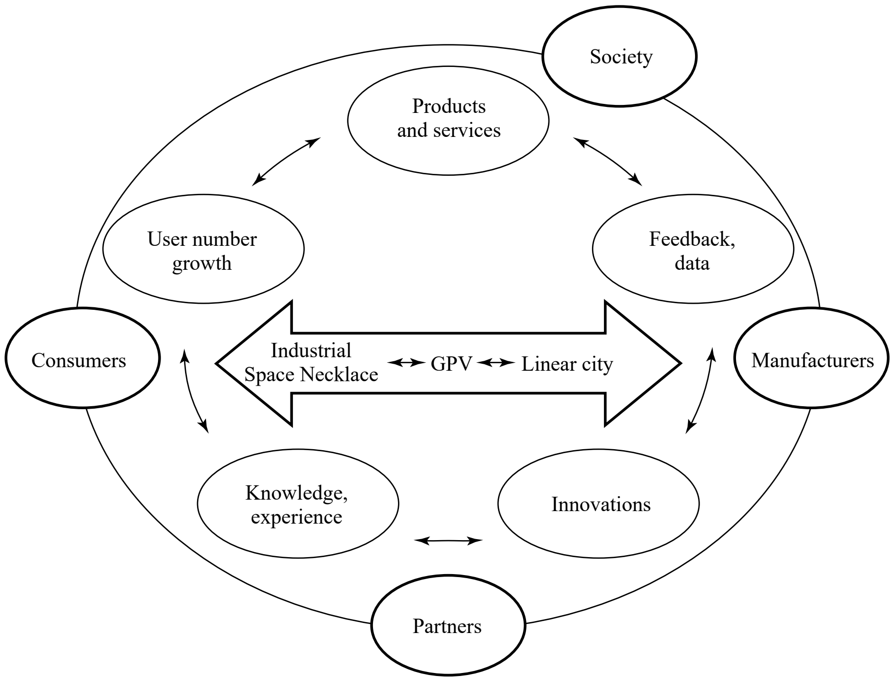

Figure 3 – Value creation process of Unitsky Space platform

D. Findings and Further Research Directions

Platforms are one of the most important economic and social phenomena of our time. Successful business in the digital era requires the right combination of physical and digital assets, understanding of how the value of the manufactured products can be enhanced through innovative data flows and user communities. The IoT will add a new level of connectivity and strength to the platforms of tomorrow while bringing people and devices together and providing new ways of value creation.

On the basis of the studied information, it can be concluded that Unitsky Space geocosmic platform has the potential of becoming the largest and most significant technological platform for the entire humankind.

Direction of further research is a study of platform culture as an analogue of corporate culture, as well as networking effects of Unitsky Space platform such as impact of the number of platform users on the value created for each of them. Positive networking effects are the major source of value and competitive advantage in the platform business.

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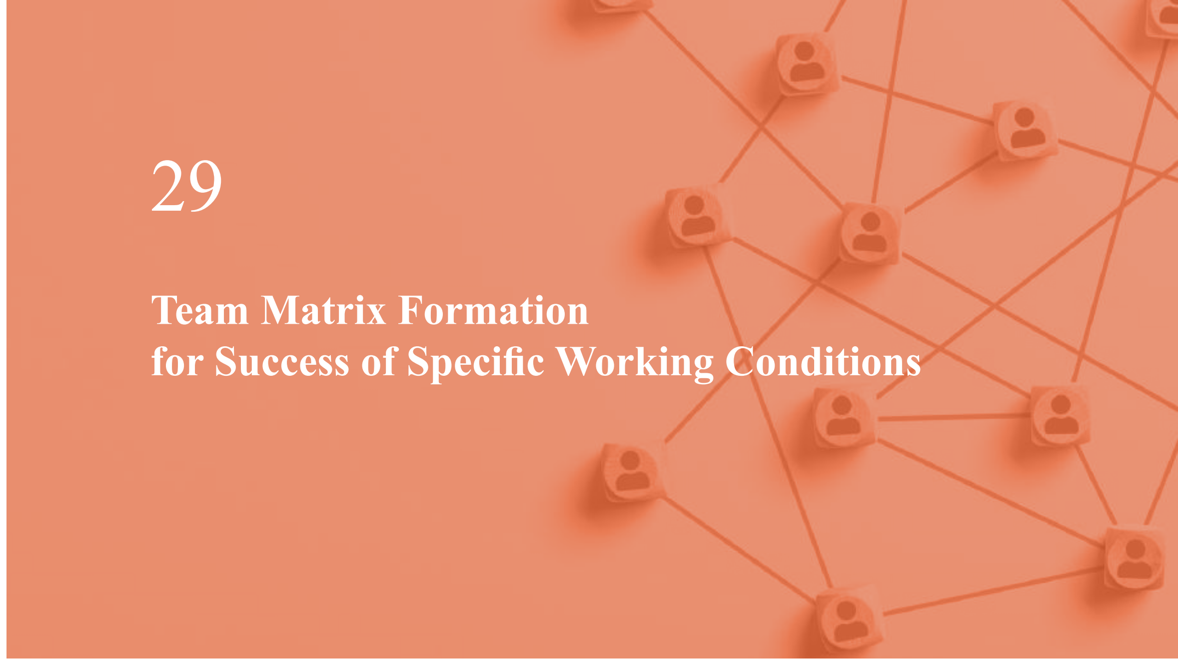

29

Team Matrix Formation for Success of Specific Working Conditions

29.1 Introduction

Labour market has changed dramatically over the recent years under the infl-ence of increasing technology development, implementation of innovations and their impact on all aspects of modern life. Nowadays, its backbone is human capital within a given company, or within a given country [1]. Investments in human resources, regardless of a longer payback period, are becoming the dominant direction for investments comparing with investments in material production, as they provide great economic advance of company or even state [2]. Global community is focused on new criteria for the future manpower development. These criteria include quick response to such innovations as automation and robotization trends, as well as principles of personal fulfi ment [3]. Usually formation of the project teams and integration of new members into the existing ones in various modern entities are going on spontaneously and unpredictably in order to meet needs of the particular time period, and that results in unaccounted financial losses, project implementation delays and sometimes even in business closure [4]. Increasing attention is given to knowledge, professional skills, experience, communication, and personality. Projects have become more complicated that requires from the staff to be multifunctional and have multitasking abilities, therewith it leads to improvement of team building approaches, as well as throughout employment of digital technologies.

A new challenge to modern methods of HR management is a need to create teams to implement comprehensive multifunctional and multitasking projects or experiments, for example, in space industry [5] or in development of enclosed ecosystems designed for human living [6]. The issue is that team flexibility is strictly limited upon the project start when all the team members have been placed within the enclosed environment and become a research object by themselves. Under this condition, all requirements to the team formation should be taken into account and evaluated even before the beginning of each particular project, since the final team has to become not only a professional body, but also a comprehensive social, psychological, communicative, and motivated unity. Formation and management of such teams is possible only when existing digital tools are combined into a single system, which is the proposed team matrix.

Section 29.2 illustrates issues for effective HR policy development, which company managers, HR specialists, and team members face. In addition, the paper reviews modern digital tools for human capital management. Section 29.3 illustrates principles and methods for team foundation and application of an optimal team matrix for projects of any complexity taking into account the teamwork issues and using advanced modern technologies. Section 29.4 summarises the main conclusions on the proposed solution, as well as directions for further research.

29.2 Review of Team Building and Management

A. Issues of Team Involvement

HR policies are an integral part of any company operation. They are intended to recruit staff with a high potential [7]. Despite existence of numerous HR researches [8] and identification of various historical stages, nowadays many issues of HR policies continue to be relevant. These matters can be divided into the following groups [9]: planning of team structure; rational teamwork arrangement; motivation of team members; team management. There are possible HR solutions in Table 1.

Table 1 – Solutions for team involvement with respect to the key problems by major groups

1. Planning of team structure	2. Rational teamwork arrangement
Forecasting of staff needs [10] Evaluation of the candidate's position matching [10]. Obligatory planning of specialists' succession [11]. Consideration of the world practice and experience in personnel expertise estimation [8], etc.	Planning and development of staff caree , their administrative and professional growth [10, 12]. Regular staff training for managerial positions, work with a personnel reserves [10, 12]. Forecast of workload changes and planning of appropriate responses [13]. Flexibility of recruitment policies under external changes [13]. Continuous training of team members and implementation of a knowledge management system [14]. Management of internal communications [14]. Identification of untapped staff potentia and management of its fulfilled scope [8] Creation of respect, trust, and honesty atmosphere [8, 15], etc.

The end of Table 1

3. Motivation of team members	4. Team management
Creation of conditions providing staff development, acquisition of desired skills and abilities [13, 15]. Flexible incentive pay plan [12]. Mechanism for employees' involvement in the company management [12]. Strategic career management system [12]. Correspondence of the staff involvement methods and ranges with their personal needs [13, 15]. Providing the environment for creative solving of problems and generation of innovative ideas [15]. Other significant opportunities for the team specialists	Regular assessment of the labour potential, compliance of their abilities with the requirements of particular positions [13]. Free access to the evaluation results [13]. Maximum employment of the staff abilitie and creation of appropriate socio-economic and production conditions for such employment [13]. Development of position improvement strategy for each employee [13]. Assessment of the company's corporate culture and the employee's corporate identity [16]. Evaluation of the specialist's sanguineness and his involvement in the company's being [16], etc.

Solution for the problems descripted in Group 1 is presented in the numerous research papers [8, 10, 11], and it includes shrewd planning of all steps beginning from the team creation stage and over the course of its operation, as well as performing of comprehensive assessment of the candidate during selection stage regarding world-known experiences in profi iency requirements and specifi project objectives.

Comprehensive assessment of the future candidate should include analysis of his/her potential, including psychophysiological (type of nervous system, temperament, health status, working capacity), qualification (general and special knowledge, skills and abilities, experience), and social-personal (value orientations, personal maturity, social activity and adaptability) aspects [8, 13, 17]. Optimisation of the candidate strengths and potentials has direct impact on his/her achievements in the company.

Earlier, candidate selection process for a certain position was based only on estimation of his/her qualification, and it has still prevailed in some companies. However, according to the modern trends such matters as cognitive and social-behavioural skills, adaptability, and other traits (for example, logical thinking and self-confidence) have come to the forefront [1] and are mainly required for multitasking and decision making positions. Therefore, since 2001 in developed countries proportion of the employees who aren't engaged in routine operations has increased from 33 % to 41 %, and in the emerging economies it has changed from 19 % to 23 % [1]. Also, such trend will increase the company's income. For example, in Vietnam, the employees who can perform analytical tasks earn approximately by 25 % more than those who are engaged in routine operations [18].

There is a special approach called competency-based, that allows to evaluate and predict contribution of a new employee to a project on the base of his/her competencies analysis and correlation of these data with the company's strategy [19]. The competency profi e which includes required knowledge, skills, motives, personal qualities of the candidate, and levels of these characteristics and behaviouristics indicators should be developed. The main disadvantage of this approach is its labour intensity requiring signifi ant time and fin ncial expenses from the company side, that are rarely compensated because there is no an integral system to process the obtained data.

Group 2 consists of tasks on the employee's career and professional growth, education, knowledge management, forecasting of workload changes, plans for appropriate response, management of internal communications, and fulfilment of all available human resources [8, 10, 12–14]. It is also important to create an atmosphere of respect, trust, and honesty within the team [8, 15].

According to the researchers, the most common approach to provide employees with additional motivation (issues of Group 3) is a flexible compensations and benefits plan. However, in most cases this method does not work singly. Table 1 lists approaches intended to build a harmonious relationship between the company and its employee in order to provide a high level of staff motivation [2, 13, 15].

Staff personal goals have a signifi ant influ nce on the process of interaction and gaining of understanding between the company and its employees. In order to develop proper HR policy, it is important to pursue personal and corporate goals in an equal manner, that should be expressed through the fair compromises in a conflict situation [10]. It is also needed to minimize staff turnover securing compliance of methods and ranges of labour involvement with the employee's own needs [13].

Solutions included in Group 4 comprise various evaluation methods to analyse the employee's professional competence and suitability for the certain position and performed tasks, labour potential and development opportunities, corporate identity and level of involvement in the company's being [13, 16].

Researchers have also noted that even if the company conducts a regular assessment of human resources, its results are rarely reported to the employees, including mid-level managers, therewith, they are not able to correct their working behaviour [16]. Commonly, such data is transferred to the company's senior staff but there are no strategic decisions made on the base of it in order to improve situation within the company.

Personnel recruiting methods regarding projects with difficul working conditions have some specific features. For instance: work in the Arctic territories [20, 21], on board of long-distance ships [22, 23], in space industry [5, 24, 25], in experiment enclosed ecosystems [6] is connected to a strong stress of the body adaptive system and health risks, as well as it means that each specialist is responsible towards the others not only for the company objectives, but also, in some cases, for their life support.

Herewith, the candidate to work in an enclosed social system similar to the above mentioned projects should be considered according to the following criteria: candidate's emotional control, attentiveness, caution, sociability, extreme behaviour, ability to do monotonous work, advanced technical and abstract thinking, resistance to stress, strength, and will [20–22]. The person shall be prone to such work, it is typical for romantic and adventurous people interested in unknown and innovative things, this fact was noted by the researchers in the course of testing the specialists who were selected for work in the North [20]. Through such type of employment people can

realise their internal psychological needs (taste for adventure, search for a better life, change of scenery).

In the course of team formation for certain complex international projects, there is also a challenge connected to effective operation of a multinational team, where specialists speak different languages, as well as represent different religious confessions and cultural traditions [22]. In this case, skills of interpersonal communication, empathic abilities, tolerance, adaptation to cultural diversity, and ability to organise work of such international teams become significant aspects for the employee selection.

In science-based and high-tech companies dealing with innovations the common issue is to determine the right combination of experienced employees who can quickly get involved in work process, but sometimes it is difficul for them to turn themselves from old standards to innovative thinking, and young specialists who need to be trained, but they are faster react to a new way of life and are ready to underwork [21]. The possible solution is based on close cooperation with the leading universities within the industry (participation in educational processes, providing of internship programmes for students and teachers at production sites), as well as creation of the company's own training and retraining programmes for qualifie specialists [25].

One of the key difficultie relating to team working in enclosed-system-type projects is proper initial planning and hiring of the required specialists. It is needed to simulate all the processes taking place within the system in order to obtain complete information about required skills, qualities, experience, and characters of employees selected for the team. In so far as the system will be isolated, it is impossible to add or exclude any team position after beginning of the project. Exercise of team creation methods for projects connected to enclosed ecosystems on Earth [6] will provide future confi ence regarding formation of teams, labour personnel, and even states for space orbit colonies [5], and then for enclosed social settlements traveling in outer space in search of habitable planets.

B. Current Tools for Human Capital Formation

All the mentioned problems relating HR planning and managing are of importance in the course of human capital formation. Therewith, current staff management tools do not meet all the present requirements because they are still at the stage of updating [26]. This has become evidenced through the difficultie faced by companies in the situation of COVID-19 pandemic and forced self-isolation of employees caused by it [27]. New technologies have radically changed the market approach to various issues, including formation of teams, labour collective, and human assets [28], that results in a constant revision of the used methods. Modern scientific literature contains a significant number of studies devoted to theoretical and practical issues of digital technologies and intelligent systems used in HR formation and management [28–31]. Automation and robotization of the processes, Artificial Intelligence, Blockchain, Big Data, the Internet of Things, and Virtual Reality are among the typical digital technologies and intelligent systems used in HR sphere.

Automation and Robotization

Automation and robotization of HR processes will increase accuracy and efficien of performed procedures, while reducing financial costs [26]. Such approach is used to optimise the procedures connected to data input and processing (for example, arrangement of data about the employees), as well as to conduct automated video and audio interviews, personnel testing, and assessment of the skills [20].

Artificial Intelligence

Artificial Intelligence (AI) significantly improves process of candidates' selection and recruitment, supports candidates' CVs monitoring and screening on third-party resources according to the required parameters [26]. Due to mathematical prediction AI analyses characteristics of the employee required for a certain position, and creates a guidance helping to choose the best candidate from the submitted CVs [30]. The system with the use of special algorithms processes data obtained in the result of pattern matching in order to determine the job seeker's character traits, mood, honesty, and other characteristics, such approach excludes intuitive analysis performed by a man [32].

The main drawback of AI technologies employment is lack of ethical dimension in the course of selection, that may result in discrimination of different social groups [26]. Surveys show that HR specialists are suspicious of digital technology employment found everywhere because in some cases it cannot replace a specialist's abilities and thinking.

Big Data

Big Data is a method of processing large volumes of structured and unstructured information distributed over numerous data channels [33]. It is intended to make digital profile of specialist while filling out his detailed portfolio with all known and necessary information. That can significantly reduce time to input necessary data and improve analysis quality of personnel assessment and certific -tion processes. Upon the candidate's permission to process his personal data from various sources, the employer may replenish the digital portrait of the applicant with information from, for example, social networks and other Internet resources, while comparing it with data from the submitted CV and getting a more complete insight onto the specialist, including the information about his habits, views, preferences, range of interests, as well as committed crimes, convictions, fina -cial and other obligations, employment of his relatives in competing companies, etc. [33, 34]. Within science-based high-tech organisations Big Data technologies provide minimizing of personnel, economic, and informational risks, as well as competitive recovery of the company via effective operation of HR management system.

The current challenge of Big Data tools is complexity of their technical design and high cost [33], as well as issues regarding legal responsibility for collecting confidential information about the specialists and employees' fears and concerns of use, storage, and security of their personal data submitted to the company [34]. At the same time collected data are not used to the full from over lack of technical solutions relevant to a particular company or project within existing software packages.

Blockchain

Blockchain technology increases information security and can be used together with Big Data technology in order to create a single data system on the employees' education, qualifications, work experience, and successes [26]. Reliability of such data storage technology also improves cybersecurity of the entire company.

Internet of Things

The Internet of Things (IoT) tools is intended to collect and organise various data about employees, including labour productivity, health assessment, emotional state [26], moving around the office and time spent in a particular offic zone [32]. However, the ethical issue limits widespread implementation of such tools within the enterprises.

Virtual Reality

Virtual Reality (VR) technologies are intended for training and adaptation of new employees [26], including training in potentially dangerous conditions (for example, training of fi efi hters, pilots, doctors, astronauts or production engineers). VR training of the employees saves the company's funds, which could be spent on tutors, training equipment, travels, and internships for specialists [29]. Therewith, this tool is useful for demonstrating skills of the candidates at the initial selection stage.

Introduction of information technologies into the personnel management system allows to reduce time and financial costs [26], cut paper reporting work (by 72 % according to statistics [30]), free up resources for development of strategies for working with human assets, form a comprehensive representation of the business including data of the company's HR capital [35]. However, current methods of HR management automation need to be updated, adapted, considered, and tested [28]. And largely it is resulted from the difficultie in processing of formalized and non-formalized data, assessment of which may be subjective [35]. It is important to consider such characteristics as adaptability, stress resistance, ability to team working, and other similar psychological qualities that are difficult to be expressed in n erals.

Despite many advantages of modern technologies, they are helpful only if there are technical and professional opportunities for their employment to the full during the collected data processing, as well as integrated system for further working with these data. For large companies and complex innovative projects, advanced HR management system subject to internal characteristics of the enterprise can become a key

tool for data aggregation in order to provide the optimal team matrix and achieve the company's goals.

29.3 Principles of Team Matrix Formation and Its Operation

Team formation in a competitive company means creation of a specific team structure, unique labour potential, accumulation and development of distinctive human capital assets. Herewith, a real challenge to the current digital methods is issue of team formation for diversified and complex projects, for example, connected to space exploration.

For comprehensive projects, experiments, and researches, it is required to create a team matrix that will support the team working process at all stages. Team matrix is a structured database relevant to the project main objectives and values. Subject to analysis of the current HR management tools it has come out that the mentioned data base should be functional at all team working stages, including beginning of the project and its continuous management.

Stages of work on the team matrix are illustrated in Figure 1.

Figure 1 – Stages of work on the team matrix

Stage 1 is matrix development. Many researchers outline that development of the correct personnel policy is based on a general mission of the company, its strategy, philosophy, and priorities [10, 19], which should be considered as an initial data. The fin l result (FR) of the project implementation or functioning of the company is determined on the base of its mission and called its main goal. For example, successful functioning of geocosmic transport system that carries cargos on Earth – Orbit – Earth route is the final result of development, establishment, launch, and return of the General Planetary Vehicle (GPV) [5].

A combination of intermediate results (IR) leads to FR, their number, and content depend on the project complexity, scale, specifications. Completion of IRs depends on the corresponding functions (F) performed by the certain specialists. All these aspects constitute the initial data for team matrix formation. Therewith, subject to a structured plan of the needed results and relevant functions, it is possible to determine essential characteristics for the specialists (qualifications (Q), health (H), psycho-emotional state (PE), social and personal qualities (SP)) in order to achieve FR and implement the company or project mission. The structure of the team matrix is shown in Figure 2.

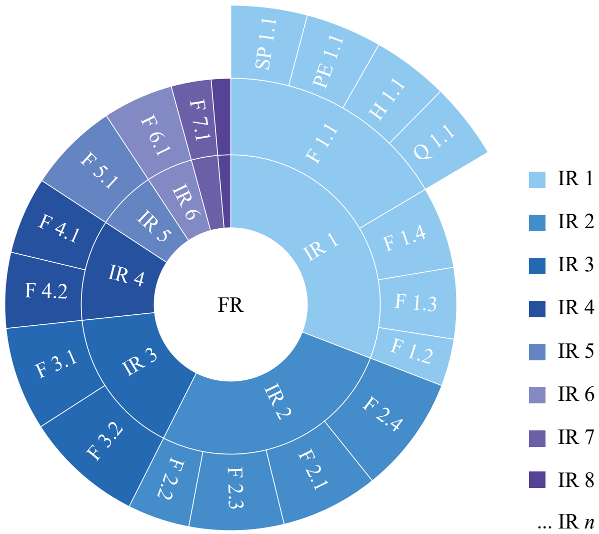

Figure 2 – Team matrix structure

A further parameter for matrix development is time needed to achieve IRs while executing a particular function. Therefore, this parameter can be set as an exact time interval (for example, ten days per eight hours a day), an indefinite period of time (two hours every day), or repeating periods (three days per eight hours a day out of every six months).

Thus, the main matrix elements are results, functions, specialist's characteristics and time. It is worthwhile noting that the matrix is bounded not to a particular position with certain assigned tasks, but to actions resulting in completion of IRs and FR. That's why a proper team matrix can be formed only when the project managers clearly understand results needed to be achieved, have a developed strategy for actions with determined deadlines and labour costs. Therefore, team matrix formation is a follow-up to the project implementation plan with definition of the product or company life cycle. Matrix development stage is intended to solve the above-mentioned first group of problems related to the team working

The above competency-based approach is well suited to define the required personnel qualities. First of all, the system considers competencies that are essential for the project mission completion and relevant to each employee. For instance, the key specialists' qualities in the service companies are customer focus, friendliness, punctuality, the specialists in research projects should be defi ed by analytical mindset, patience, scale and flexibility of thinking, breadth of knowledge, for programmes implemented in difficul conditions such qualities are emotional control, attentiveness,

sociability, stress resistance, and so forth. Hence, the list of required characteristics should be settled in relation to each particular function.

Table 2 shows a competency-based component of the matrix with specifie parameters of qualification, health, psycho-emotional state, and social-personal qualities.

Table 2 – Competency-based component of the matrix regarding aircraft piloting specialist

Intermediate result: aircraft takes off from point A and successfully lands just in time in point B	
Function: aircraft piloting	
Qualificatio	Professional education, training, experience
Health	Sound health, good eyesight, colour discrimination. This position does not suit for persons with impairment of vision, vestibular system, as well as nervous, mental, and cardiovascular diseases that may result in loss of consciousness
Psycho-emotional state	Emotional control, attentiveness, carefulness, enhanced technicial and abstract thinking, stress resistance, strength, will, patience, reaction rate, good memory, capability to perform monotonous actions for a long time
Social-personal qualities	Desire to participate in comprehensive projects, romantic and adventurous person, striving for something new, unknown, and innovative; sociability

Intermediate results can be divided into several levels, as well as separated into blocks taking into account the activity sphere. Towards complex projects there will be a lot of blocks relevant to different areas of the project and its stages. For example, in the course of the construction project implementation such stages as pre-design and design work, construction, commissioning, and maintenance are considered separately. Matrix details depend on required accuracy and quality of the following processes: selection of team members and management of staff achievements with the use of mentioned system.

Upon fi ling out the matrix we received a detailed data base for various activities. As a rule, a number of functions prevails over a number of employees, therewith it is obvious that one employee may perform a number of functions. Subject to the initial data (Table 3), set deadlines and using automated software products, it is possible to obtain combined team profiles (example is shown in Table 4), in which various functions are assigned to one or more specialists.

Table 3 – Initial data for team profil

Intermediate result 1		
Functions	Required time	Required personnel qualities
1	2	3
F 1.1	2 h per each working day	Q: "A" H: "a" PE: 1; 2; 3; 4 SP: I; II

The end of Table 3

1	2	3
F 1.2	10 days per 8 h a day	Q: "B" H: "b" PE: 1; 4 SP: II; IV
F 1.3	3 days per 6 h a day out of every 6 months	Q: "A" or "C" H: "c" PE: 3; 4; 5 SP: I; II; IV
F 1.4	20 days per 4 h per a day	Q: "B" or "S" H: "b" PE: 1; 2; 4; 5; 6 SP: II; III

Table 4 – Example of compiled team profil

Intermediate result 1			
Specialist	Specialist qualification	Functions list	Work schedule
Specialist 1	Q "B" – obligatory Q "S" – additionally H "b" PE 1; 2; 4; 5; 6 SP I; II; III	F 1.2 and F 1.4	20 days per 4 h a day for F 1.2 and F 1.4 (in total 20 days per 8 h a day)
Specialist 2	Q "A" – obligatory Q "B" – additionally H "a"; "c" PE 1; 2; 3; 4; 5 SP I; II; IV	F 1.1 and F 1.3	2 h per working day for F 1.1 and 3 days per 6 h out of every 6 months for F 1.3

These profiles can be used to distribute tasks between members of the existing team (subject to data collected with the use of Big Data, IoT tools, and other automation HR management systems), or to create a new team, when a well organised profiles help to find the best candidates for particular positions (Stage 2 of working with the matrix). Moreover, the proposed team matrix can be applied for forming teams for small projects, as well as for large corporations. For complex long-term projects, it is preferable to base the matrix on various stages of the project or the whole enterprise life cycle. With the use of this tool, you can predict development, training, and career growth of specialists, transformation of their functions according the project requirements, and create a motivating system for the employees (solving problems describes in Groups 2, 3). The abovementioned aspects enable flexibility of the technology in the course of the company growth.

Developed concept of specific indicators results in a clear structure and a manageable system, which will allow to carry out Stage 3 of working with the matrix, i.e., management of personnel work and project implementation. Adding of achieved work results, indexes of staff competencies development, additional skills, and experience

of the specialists into the presented matrix with increasing time will provide assessment of the employees and the enterprise potential growth. In such a manner corporate identity of each employee, his professional activity, pursuance of self-development are analysed. Team matrix data available not only to the managers, but also to the employees, simplifies HR management within the compan .

For projects connected to an enclosed social system, where it is needed to arrange conditions for a high-quality life and work in space [5, 6], the formed team matrix is a necessary tool at various stages of managing staff and social structure of the formed society. Along with adaptation of biological systems, formation of trophic links and establishment of self-regulation of an enclosed ecosystem, it is important to adapt and test the founded social structures and institutions to ensure establishment of a self-sufficien autonomous team for long-term (for several generations) space projects. The initial adaptation and approbation of these teams should take place on Earth, and it is needed to employ flexible tools for planning, establishing, and managing the entire system. The matrix includes parameters of social communities and institutions with plans and forecasts of their sustainable development, as well as the characteristics of the selected specialists. Upon start of functioning of the autonomous space settlement prototypes, the system changes are fixe in the matrix, its predictions are adjusted, and if it is necessary, solutions on revising of the initial plan in order to achieve the set goals and preserve the harmonious sustainable development of the created society are developed.

Creating of a team matrix is a complex process, but the major scope of work is carried out during the initial stage, when a great amount of information should be entered into the system. This stage provides development of the strategy and plan on the project implementation. Thereby, the generated system will support and assist in completion of the project mission, as well as become a released software product for further development of team matrix for other activities, including commercial employment.

29.4 Conclusions and Future Work

For successful implementation of various complex projects in the rapidly changing world, it is necessary to use relevant and eff ctive tools for HR management, knowing that human assets perform the main value of any modern enterprise. Optimal team matrix for achieving the project goals in conjunction with current digital technologies and intelligent systems may become a universal tool to meet all the requirements. It will solve issues on resources planning, formation, and management of project teams, as well as structuring collected data and automating HR management processes. For complex projects related to an enclosed social system, the developed team matrix can become a tool to study ways of formation and adaptation of social structures and institutions in accordance with specific needs. The raised issue of autonomous society creation and development is of great interest due to its prospects in the space industry. Nowadays, experience in social structures creation is limited by terrestrial conditions and long time periods required for their formation and progress, this exclude possibility to consider such systems as complete analogues to the space ones.

Further work on the topic will concentrate on studying and development of solutions for creation of enclosed social systems in autonomous space settlements, as well as choice of the optimal institutional structure of the society which is integrated into the estimated conditions and appropriate management systems necessary for harmonious and sustainable development of the society and each particular individual.

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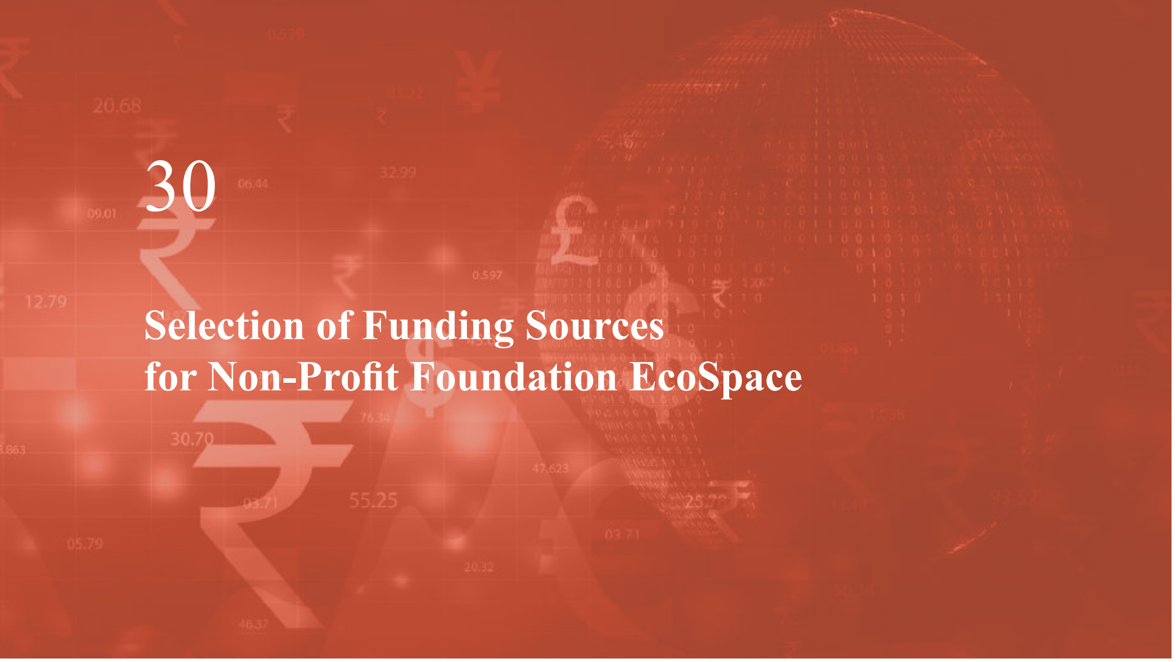

30

Selection of Funding Sources for Non-Profit Foundation EcoSpace

30.1 Introduction

Non-profit organisation does not have a goal to make profit and the profit obtained is not distributed among the participants. For a non-profit organisation to have a reliable and sustainable operation, a stable long-term source of funding is required. Due to inflexible structure of the financial support system, non-profit organisations often face a problem with the unavailability of finances for project implementation. Therefore, it is critical to correctly identify the main sources of revenue for a non-profit organisation. The purpose of the paper is to create a concept of fin ncing a non-profit company engaged in activities aimed at solving global environmental problems and saving humankind by relocating harmful industries beyond the Earth's biosphere to the near-Earth orbit. The authors also consider options for providing fina cial support to non-profi organisations and methods of fin ncing programmes dealing with space exploration.

The relevance of this topic is that the selection of subsidizing sources pays a major role in the development of non-profit foundation EcoSpace. The mission of this foundation is to implement engineering solutions that will allow to cope with the most acute global problems of humankind, such as environmental pollution, misallocation of resources and violation of the principle of biosphere sustainability.

Main objectives of EcoSpace foundation are as follows:

- health of a person in particular and of society as a whole;
- preserve the nature as a human habitat;

- focus on family values and life of future generations;
- preservation of the living diversity;
- unlocking the inherent human potential through new technologies of space exploration [1].

The chapter raises the issue of choosing the most sustainable and reliable sources of funding for the foundation EcoSpace.

30.2 Overview of Funding Sources of Global Well-Known Non-Profit Organisations, Whose Objectives Correlate with Those of EcoSpace

Table shows the methodology for selection of funding sources for non-profit foundations within the selected scope.

Table – Funding sources for non-profit foundation

Name	Year of incorporation	Focus of activities	Budget	Funding sources
1	2	3	4	5
WWF (World Wildlife Fund)	1961	Prevent the increasing degradation of the planet's natural environment and achieve harmony between humans and nature. The main objective is to preserve the Earth's biological diversity	Revenues 2019 – 308,292,650 USD: • individual donations – 39 %; • donations in kind/ others – 26 %; • government grants – 11 %; • foundations – 8 %; • social media – 6 %; • contributions from non-operational activities – 6 %; • corporate contributions – 4 %. Expenditures 2019 – 308,400,477 USD: • programmes – 81 %; • administrative costs – 6 %; • fundraising – 13 % [2]	Individual donations Government grants Donations in kind Donations from foundations Social media Contributions from non-operational activities Corporate contributions

The continue of Table

1	2	3	4	5
GreenPeace – an international, independent, non-governmental environmental organisation	1971	Confronting systems that threaten the environment	Revenues 2018 – 360,084,000 EUR: • grants and individual donations – 98 %; • others – 2 %. Expenditures 2018 – 220,661,000 EUR: • programmes – 71 %; • organisational support – 26 %; • losses on currency exchange rate – 3 % [3]	Exists only on donations of citizens and private charity foundations, does not accept money from state, commercial organisations and political parties
FoEI (Friends of the Earth) – an international network of environmental organisations	1969	Activities are focused on ensuring environmental and social justice, human dignity, respect for the rights of every person and group of individuals; preventing environmental degradation and depletion of natural resources; enhancing the environmental and cultural diversity of the Earth	Revenues 2018 – 3,402,952 EUR: • grants – 80 %; • membership fees – 19 %; • donations – 1 %. Expenditures 2018 – 3,505,248 EUR: • programmes – 39 %; • management – 8 %; • administrative costs – 6 %; • fundraising – 3 % [4]	Grants Membership fees Individual fees
FSC (Forest Stewardship Council)	1993	Monitoring the development of global standards for responsible forest management (forest certification	Revenues 2018 – 37,325,000 USD: • annual administrative fees – 79 %; • donations – 2 %; • ASI revenue – 15 %; • commercial fees – 2 %; • membership fees – 1 %; • others – 1 %. Expenditures 2018 – 33,728,000 USD: • personnel – 28 %; • travel expenses – 8 %; • with third party participation – 59 %; • operational costs – 5 % [5]	Main income – contributions from certificate holders (for sale of wood)

The continue of Table

1	2	3	4	5
EDF (Électricité de France S.A.) – France's largest state-owned power generating company	1967	Preservation of natural systems. Solving the most severe environmental issues.	Revenues 2019 – 202,755,192 USD: • donations and membership fees – 68 %; • donations from foundations and other institutions – 23 %; • investments/ other income – 4 %; • legacy assets – 4 %; • grants – 1 %. Expenditures 2019 – 201,343,856 USD: • programmes – 82 %; • others – 18 % [6]	Donations and membership fees Donations from foundations and other institutions Direct investment Legacy assets Grants
Global Nest – an international association of scientists, technologist, engineers, and other specialists	1997	Advancing the study of environmental sciences, technologies, and politics; maximum possible spread of knowledge on environmental science, technologies and politics; exchange of information among scientist and academia, business, industry, politicians, and general public	Revenues 2019 – 84,239,000 GBP: • grants – 18 %; • donations and annual administrative fees – 81 %; • others – 1 %. Expenditures 2019 – 127,854,000 GBP: • personnel – 15 %; • amortization – 7 %; • administrative and investment costs – 56 %; • interest payments – 22 % [7]	Grants Donations and annual administrative fees
IRENA (International Renewable Energy Agency)	2009	Maintaining widespread implementation and sustainable use of all forms of renewable energy sources to achieve sustainable development, access to energy, energy safety and low carbon economic growth and prosperity	Revenues 2014 – 41,899,000 USD: • mandatory contributions – 48 %; • voluntary contributions – 43 % • contributions in kind – 8 %; • revenues from investments – less than 1 %; • others – less than 1 %. Expenditures 2014 – 35,258,000 USD: • personnel – 42 %; • consultancy services – 29 %; • meetings – 12 %;	Mandatory contributions Voluntary contributions Contributions in kind

The end of Table

1	2	3	4	5
			• travel expenses – 3 %; • operational costs – 11 %; • amortization – 3 %; • losses on currency exchange rate – less than 1 % [8]	
Non-profit o ganisation for space exploration				
The Planetary Society – an American non-governmental non-profit organisation	1980	Enhancing the capabilities of humankind in space sciences and space exploration	Revenues 2019 – 5,822,428 USD: • donations – 40 %; • revenues from investments – less than 1 %; • membership – 57 %; • others – 1 %; • sales – 1 %; • specific events – %. Expenditures 2019 – 4,927,577 USD: • programmes – 66 %; • management – 17 %; • fundraising – 17 % [9]	Donations Revenues from investments Membership Sales Specific event

30.3 Revenue and Expenditure Structure of Non-Profit Foundation EcoSpace

Based on the analysed options of funding sources for non-profit organisations in the field of ecology, environmental protection and space exploration, the authors of this paper have identified the structure of revenues and expenditures for the non-profit foundation EcoSpace (Figure 1)

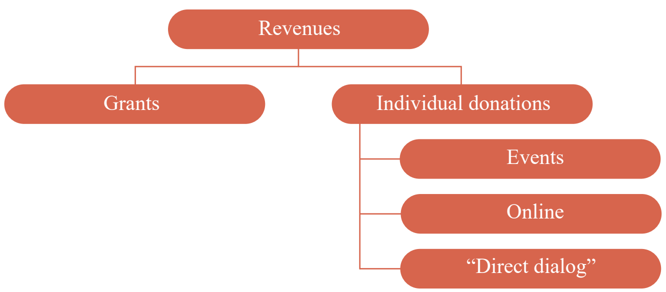

Figure 1 – Revenue structure for non-profit foundation EcoSpac

Grants. This source of funding is intended to receive non-reimbursable funds from private and public foundations for the implementation of EcoSpace project. Grant sponsors may be state-owned or private. Grants are paid out by various foundations on a competitive basis. In order to receive grants, it is necessary to decide on the foundation and make a proper application in accordance with its requirements and recommendations [10].

Individual donations. According to data at Charity Navigator, in 2017 individuals have allocated more than 286 bln USD, which is 70 % of the total amount of donations. This means that individual donations are the most significant source of funding [11].

Donations from individuals can be collected in the following ways.

- **Events.** It can be festivals, exhibitions, balls, lotteries, concerts, auctions, sales, dinner parties, etc. Usually, a common scenario for holding an event is used: determine the target audience for which the campaign is developed; determine the approximate amount of funding that the organisation plans to collect; carry out the preliminary work (a special emphasis is placed on the media); develop printed materials and a package of advertising products, after which the campaign itself is carried out. Then, it is followed, as a rule, by a progress report in one form or another, which expresses gratitude to all those, who took part in the event.
- **Online.** This key way of collecting individual donations should include: mailing lists; donations through websites (the organisation’s website and aggregator websites, including crowdfunding); Internet auctions; blogs and other live journal services; mobile applications for making donations; attracting donations through social networks and other web-based interactions.
- **“Direct dialog” donations.** The essence of this method: volunteers or employees approach people on the street, individually telling them about the organisation’s activities, giving examples, getting their interest and explaining how that particular person can help (by making a private donation). However, despite its effe -tiveness (achieved through targeting and live human communication), this method requires significant resources and some training. It should be noted that the payback is not straight off; it is quite a lengthy process, which takes about 1–3 years. Thus, the organisations should have funds for investments and consistent work with the regular donors.

The expenditure structure for the non-profi foundation EcoSpace is given below (Figure 2).

Implementation of projects. According to the analysed expenditure structure for non-profit organisations, the main part is the implementation of foundation’s projects and programmes.

Administrative and household expenses. These include personnel remuneration, costs for maintenance and operation of office spaces and busine   trips.

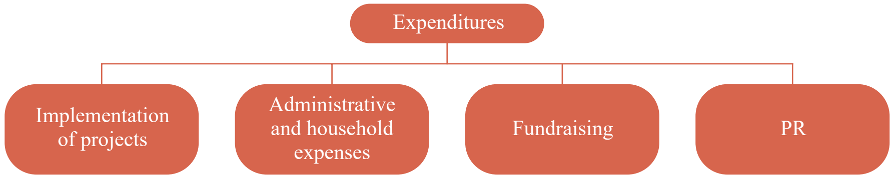

Figure 2 – Expenditure structure for non-profit foundation EcoS ace

Fundraising. Fundraising is, broadly speaking, attracting not only money, but also connections, goodwill ambassadors, media support, and creating foundation-based network. Both individuals and companies, as well as state-run organisations can act as giving parties.

Fundraising managers use various methods to achieve the objectives of a non-profit foundation, namely

- participate in joint projects and reception of target funding under programmes of international organisations;
- participate in projects funded by the state. The advantage is a formation of the basis for social partnership between state structures and non-governmental sector, which, in its turn, develops mutual interest and focus on long-term cooperation;
- organise special fundraising events (charity nights, auctions, concerts, sports competitions). The positive side of this instrument: it gives the opportunity to meet many potential donors and to attract like-minded people at the same time;
- attract volunteers. This method advantage is created by volunteers – people, who donate altruistically their time, knowledge, professional skills for noble objectives of the organisation;
- personal meetings. Although this method is time consuming and requires high professional skills of a fundraiser, such meetings are an effective tool since the help is provided by a person to person rather than by an organisation;
- use Internet sources. The main advantage is the possibility to search for potential donors, to publish your own web-pages with a description of the objectives and programmes of the organisation;
- advertising. Often ineffective method, although it covers a large audience. Advertising can be in the form of publication of specific articles – media appeals, videos shown at special events, installation of billboards, distribution of booklets and calendars. One of the modern types of advertising is the publication of banners on Internet portals, mailout [12].

PR. An important focus is on creating a positive image and drawing attention to the foundation. PR-activities of a non-profi organisation are based on maintaining the prestige of a non-profi foundation at all levels by informing about activities useful to citizens, promoting its projects and seeking donations for their implementation.

30.4 Main and Additional Funding Sources for EcoSpace Foundation

According to the analysed data, individual donations should be considered as the most significant source of funding for the EcoSpace foundation. This option of funding is used by many non-profit foundations and it is seen as the most effective Therefore, it is reasonable to focus on individual donors and make them the central focus of the foundation's strategy. In addition, the non-profit foundation should be open and transparent, which will establish trust in its activities and encourage the activation of more private donations.

It is also worth paying attention to the grants that may be received from the other foundations. Grants enhance the foundation's, which will contribute to the receipt of increased non-profit funding from other sources

However, the drawback is that such donations are intended for specifi short-term goals rather than for constant non-profit income flo . With this in mind, grants can be used as an additional source of financial support

As for the expenditure structure: 80 % of the budget should be spent on implementation of the foundation's projects. In turn, balance 20 % of the budget will support the foundation's activities, including the cost of qualifi d personnel, as well as image making and PR campaigns (Figure 3).

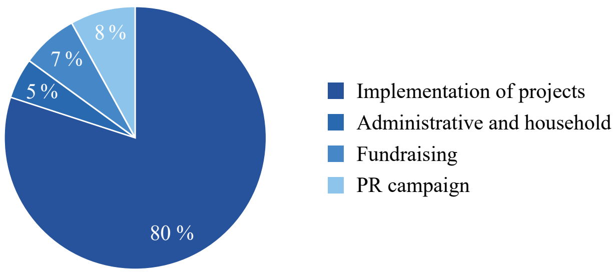

Figure 3 – Budgeting of non-profit foundation EcoSpac

It is critical to make the brand recognizable to its target audience. It is PR campaigns and mass media that promote corporate ideas, which attracts attention from the public, as well as they act as the means to ensure the functioning of the organisation. In addition, the expenditure structure includes fundraising as the main source of financial sustainability of the non-profit foundatio

The primary sources of funding for the EcoSpace foundation have been identified in the course of this study, as well as revenue and expenditure structure has been developed. Practical recommendations on selection of the form of funding for the non-profit foundation have been given

The direction of further research is a detailed study and evaluation of the effe - tiveness of the EcoSpace non-profit foundation activities

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Modern human civilization has built its foundation on the unsustainable platform of hazardous industries. Such an approach led to significant damage to the E rth's biosphere.

Anatoli Unitsky – the principal author – discusses the historical retrospective of the key problems of changes in the biosphere because of negative impact of a technocratic civilization. The author focuses on the direct harm and low efficienc of the rocket-based space exploration methods from ecological and financial perspectives.

Dr. Unitsky suggests two pioneering principles to completely solve the environmental situation on the planet, as well as various economic and social problems: development of a self-moving up and down transport ring covering the globe at the equator (in particular), as the General Planetary Vehicle (GPV); development of a stationary ring in orbit for permanent residence and large-scale implementation industrial activity in the interests of the whole planet.

The developing solutions are based on ecologically oriented and efficient technologies

The book comprehensively and systematically addresses the issues of building transport and stationary industrial systems, considering the potency, safety, and comfort of operation and living. Besides, the presented knowledge is multidisciplinary: engineers, architectures, biologists, chemists, sociologists, politologists, lawyers, and economists have analysed and developed the corresponding aspects of A. Unitsky's concepts and presented their visions and results in this monograph.

Scientific Publicatio

Anatoli Unitsky (Chief Editor)

System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects

Coordinators: Sergey Artyushevskiy, Nadezhda Yerakhovets, Sviatlana Auchynnikava
Editors, Proofreaders: Larisa Gilmanova, Tatiana Linevich
Translation: Ilya Kavalchuk
Translation Editors: Yulia Grinevich, Nina Lanina, Sviatlana Auchynnikava
Desktop Publishing: Inna Lud, Vera Bespalova

Materials from open Internet sources are used for this publication.

Signed to print on July 7, 2021. Format 70 × 100 1/16. Enamel paper. Offset printing
Conventional printed sheets 46.15. Published sheets 26.6. Circulation 1000 copies. Order 779.

Ordered by A. Unitsky.

Printed of the original layout at GRADIENT®, NAVITEH LLC.
Certificate of SROPPPPD No. 2/194 of 23.07.2017
6a Babushkina Str., Minsk, 2200024.

Publisher: LLC Advertising and Information Agency VECHERNIY BREST.
Certificate of SROPPPPD No. 1/414 of 14.08.2014

UDC 629.78
ISBN 978-985-7266-09-8