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Space 4.0 – a common, democratic European space, part 4

Ryszard S. Romaniuk, and Piotr Orleański

***Abstract*—One of the dominant common denominators of the Space 4.0 idea in the domain of space technologies are small satellites. The characteristic features of this group of technologies are relatively low costs, the possibility of very rapid hardware prototyping and modularization, the construction of hardware and software libraries for quick reuse, a significant number of manufactured and orbited satellites, incomparably easier ability to test numerous varieties of new technologies, while maintaining high reliability in a relatively short period of their orbital operation. It is small satellites that have become a solid foundation for the rapid development of the Space 4.0 idea. They require a completely different, much simpler ecosystem to maintain and safely, efficiently operate, especially large, highly functional microsatellites constellations throughout their life span between orbit and deorbit. The year 2012 can be considered the beginning of the development of the small satellite industry, a few years before the formal definition of the idea of Space 4.0. Small satellites and the involvement of the private sector in their production and operation were the engines thanks to which the technological and economic components of the Space 4.0 idea were defined. From the perspective and experience of over a decade of development of the small satellite industry, we look into the future and analyse trends also in terms of the situation of the space sector in Poland. A version of this paper in Polish was published in Elektronika Monthly by SEP.**

***Keywords*— space policies; Space 4.0 project; European Space Agency; space democratization; space and satellite engineering**

I. Introduction

THE OpenSpace idea means, at least theoretically, open equal access to space for all interested scientific, technological and economic entities. In our economic region, we define it, attractively and as briefly as possible, as Space 4.0. OpenSpace would not have developed so rapidly if not for several fundamental factors of a political, social and economic nature. It was understood that the space cannot be arbitrarily appropriated mainly by the military, and only by the largest companies, because it belongs democratically to societies.

The decisive factors were, and still are, maintaining the dynamics of the development of the comprehensive space sector, the complete change of satellite technologies, and the skilful foundation of the developing layer of services on these technologies. These services include various economic sectors, but also much more broadly, medicine, environmental protection, culture, social activities and others. We are witnesses to the evolution of this idea.

Many components of this evolution are common to the entire globe, but many others are exclusive and specific to space giga-regions. Our world is quite strongly divided, mainly politically and culturally, into several such giga-regions. There are quite strong boundaries between these regions, but there is also a desire for organizational, technological and service cooperation.

II. NewSpace, Open Space, Space 4.0, Open Space Society

In the series of articles on OpenSpace, NewSpace and Space 4.0 [1-4] we ask questions about opening up space and what are the consequences of the above ideas formulated not so long ago. We are particularly interested in the consequences for Poland, as a member of the EU. The Space 4.0 program prepared under the auspices of the European Space Agency ESA, and published in 2016, after several years of preparations, is the European version of the general idea of opening up space for the economy and society, which we call OpenSpace. This idea first began to develop in the USA under the name NewSpace, over thirty years ago. Currently, the idea referred to by the general term OpenSpace has covered practically the entire world. Of course, we are talking about a world that is sufficiently technologically advanced, or that part of the world that can afford to purchase its own space infrastructure. So, for now, this applies to a relatively small group of countries that are capable of independently designing, testing, producing and orbiting satellite hardware infrastructure, as well as very rich countries.

Due to economic reasons and differences in the economic and technological development of various regions of the world, it is developing quite unevenly, but still very dynamically. Here we focus on the development processes taking place in the European region and the idea of Space 4.0. We also try to understand where Poland is in these processes and what our development opportunities are. In our European space giga-region, the development of Space 4.0 is very uneven. The idea of Space 4.0, formulated only a few years ago and practically undertaken even later [5], is to counteract this unevenness and bring us evolutionarily closer to a common democratic, European space and its fair scientific, economic, service, but also broad social use. This is too short a time to significantly equalize the stages of technological advancement. In OpenSpace/Space 4.0, the correlation of the terms Industry 4.0 and Space 4.0 is not accidental and is intended to indicate the integral inclusion of near space around the Earth in the European economy, and of course including the Polish economy.

Despite the recent launch of OpenSpace/Space 4.0, terms

R.Romaniukis with Warsaw University of Technology, Poland (e-mail: ryszard.romaniuk@pw.edu.pl).

P.Orleański is with Space Research Centre, Polish Academy of Sciences, Poland (e-mail: porlean@cbk.waw.pl)

such as open space ecosystems, open space services, space factory and/or manufacturing, open space industry, space mining, space economy, space society, and even space culture are already emerging and are slowly, evolutionarily, being defined more precisely. New terms are starting to function alongside the further developed previously stabilized technologies such as space/satellite communications, space safety, etc. These processes are actively reflected in Poland in the form of organizing scientific conferences [6], expert meetings in the Sejm of the Republic of Poland [7], participation in European space programs [8], the establishment of space sector companies [9], signing international agreements for the construction of orbital infrastructure, legislative and economic government initiatives, etc. Available global analyses of the new developing OpenSpace space sector are very optimistic [10]. Most of such in-depth analyses, including the projection of many development scenarios, concern the technology of small satellites SmallSat. The SmallSat technology is currently a major driving force behind NewSpace, OpenSpace and Space 4.0.

Small satellites open up new areas of space applications but also slowly take over many areas, previously reserved for large satellites. The descent into LEO orbit and the use of constellations create new observation tools, previously unavailable. SmallSat ecosystems are being created. All these processes are reflected in numerous general and sectoral studies on SmallSat [11-20]. The considerable dynamics of the OpenSpace development processes authorize us, perhaps for now with some advance notice, to start encouragingly using the term Open Space Society. The process of building the Open Space Society that has begun has a completely different character from when the term Space Society was first used in connection with the first landing of Man on the Moon several decades ago. The current process has a truly social character, although of course these are only modest beginnings of, let us hope, a real social reconstruction.

III. OpenSpace, Space 4.0, NASA, ESA and Space Giga-Regions

The OpenSpace idea has embraced practically the entire globe in the last decade. It is being developed and implemented in various economic giga-regions in a similar, but slightly different way. Giga-regions of space technology development naturally overlap with economic and political giga-regions, which results in differences in the project implementation. Space giga-regions cooperate and compete with each other. Usually, we mention the USA, Europe, China, India and Russia as the decisive space giga-regions. Giga-regions constitute a significant force attracting larger and smaller countries with space ambitions, but unable to exceed the critical mass of the giga-region economically and technologically, even in a group of several countries. This critical mass, defined by technology and economics, is related to the independence of building a full OpenSpace ecosystem, including the possibility of effectively orbiting the hardware infrastructure, at least to the LEO orbits.

Some of these larger and richer countries with space ambitions, sufficiently strong economically and technologically advanced, however, operate independently and join their space activities to giga-regions in the case of larger projects. An example of the possible significant impact of giga-regions on many smaller countries interested in expanding their economies to the space are, for example, large space projects using microsatellite constellations related to satellite services. Another, recently growing impact is exerted by the increasing number of projects aimed at the Moon. One of such potentially very large projects with a global reach is organized by China, which currently has the interest and declaration of participation of several dozen countries and eventually even a hundred. Another large project aimed at the Moon is the Indian Chandrayaan 4 project. The multi-module mission planned for 2027 is to provide lunar soil samples from several locations. The Moon, which is close to us, and the space projects related to it are proving to be a force integrating countries and nations. In a sense, even such larger lunar ideas are currently also being incorporated into the OpenSpace ideology. In any case, the Moon is a much more realistic goal for those willing to participate in the OpenSpace processes than the incomparably more difficult Mars.

The American and European giga-regions are organizing similar projects aimed at the Moon in their areas. Of the three previously mentioned giga-regions of the United States, China and India, it seems that our region, coordinated to some extent by ESA, has provided the most modest resources for such initiatives. Perhaps Europe should seriously reconsider its space policy in the area of Space 4.0 and the correlated areas of the Industry 4.0. The space sector in the era of OpenSpace that has just begun and is being created is potentially quite complex. It contains many specialized sub-areas. The Space 4.0 guidelines correctly indicate them, but do we have the resources and strength to develop them all evenly? Is ESA prepared to coordinate such a large new sector? Up to now, it has not been prepared at all for this. And it is not making any significant effort in this direction. It is not doing so because it cannot, having too little funds, and rather focused on the research sector covering larger experiments. ESA cannot be criticized for this, such was its original role. However, times have changed dramatically and it turns out that the European space super-region lacks appropriate organizational structures adapted to new challenges. The potentially stimulating European Space Flagship sector at a typical level of one billion Euro per decade is too small an amount to induce dynamic changes in such a large and structurally complex area as the whole EU.

It is worth noting that such governmental organizations as NASA in the USA and intergovernmental organizations as ESA in Europe are not entities directly driving the development of the OpenSpace idea. It is one thing to present the dynamics of changes in the sector at the general economic and social level, the vision of development, and even strengthening and protecting certain, in this case inevitable, development trends of the space sector, and another thing is taking an active and key part in these processes. OpenSpace is giving a significant part of the space sector to private business, and to a large extent small, dispersed, and difficult to control. It is a kind of a marriage of convenience between the technological and service, space and private economic sectors. NASA and ESA are institutions that are to be responsible for large and smaller international research projects. However, it cannot be said directly that, for example, ESA neglects the SmallSat sector. ESA clearly notices the fundamental role of small satellites in the process of democratizing space [16, 19]. A separate issue, and currently more important than the formulation of new space ideologies, is the possibility of very active participation in the OpenSpacer development processes, which are to encompass the entire societies.

OpenSpace will probably complement such large projects, coordinated by NASA and ESA, with its increasingly numerous activities on a smaller scale. These activities can be both basic research in cooperation with large organizations and applied research performed on behalf of the industry. OpenSpace is the development of the utilitarian part of the space sector. NASA and ESA are about pushing the boundaries of knowledge in space, and adequate investments in people, research and infrastructure. OpenSpace complements the space sector with a component that did not exist before. The space sector is becoming complete, similar to the large sectors of the economy developed and cultivated on Earth. In this complete space sector, NASA and ESA are not agencies funding the development of an industry focused on the implementation of social services. They are mainly responsible for pushing the boundaries of knowledge. Of course, they outsource some of their tasks to the industry, but this is only a fragment of their activities.

NASA and ESA are also in a completely different political, social and economic situation. NASA has a central administration directly above it, and a large, relatively uniform economy next to it. This economy includes economic chaebols with enormous possibilities and a developed high-tech sector of companies of various sizes, including a very rich SME sector. ESA has a consortium of many different central administrations with different interests above it. There is no equality between the participants in this consortium. ESA is located in the area of operation of quite complicated structures of the European Union and the Commission and the European Parliament. Supposedly, the EU talks about the complete independence of ESA from the EU, but this independence must be periodically delicately negotiated with the specification of dynamically changing competences along with political changes and technological progress and economic development. ESA is selectively surrounded by a large economy, which results from historical conditions. The high technical and logistical standards developed in such a system often constitute a difficult barrier for new economic players. All the more so because the European economy is quite unevenly developed between individual countries and regions. The level is of course levelling out, but protectionism in the field of the highest and unique technologies is still strongly maintained in Europe. This protectionism that slows down development is, it seems, a remnant of past times and should gradually disappear within the EU.

The OpenSpace idea operates in the space sector as a high-level feedback loop that requires a different perspective on the entire area. The large research infrastructures of both NASA and ESA are getting older and there is an increasingly active discussion on their restructuring and modernization, as well as on launching new projects [21]. This is also undoubtedly a certain effect of the feedback loop from OpenSpace. The approach to the entire space sector is changing rapidly, in all areas: scientific, technical, social, economic and political. One of the strong symptoms of this feedback loop is that OpenSpace, with the growing involvement of the private sector and public interest in the space sector, shows, especially in our giga-region, how little resources ESA actually has at its disposal. How limited ESA's possibilities really are. It is possible that OpenSpace will take over the leading role in this sector in many of its regions, also partially in the scientific one.

IV. OPENSPACE AND OUR REGIONAL DERIVATIVE SPACE 4.0

Is Space 4.0 our regional derivative of the OpenSpace idea? Of course, to some extent it has been from the very beginning. However, it is a process of maturation and adaptation of an idea with a catchy name, different in Europe and completely different in the USA. State borders and interests, despite the European Community, are still visible and maintained. In Europe, there are not and will not be such strong development impulses as are present in the USA and China. Impulses at the equivalent level of hundreds of billions of Euro. In Europe, we probably have to diligently build Space 4.0 on the foundation of the SME economic platform, i.e. small and medium-sized innovative companies. Such platforms are quite unevenly developed in individual EU countries. Space 4.0 will slowly become more ours if we are able to overcome regionalisms and equalize technological opportunities. It will become ours if we comprehensively develop competences in our country. Space competences (and others in the area of high technologies) are staff, laboratories, industry, applications, services, and more.

The process of opening up and the opening of outer space itself are very complicated processes and susceptible to many political and economic factors. In this regard, let us return once again to the sentence that opens this article, with a slight change about the potential nature of such a wide opening of outer space. The idea of OpenSpace means potentially open, equal access to outer space for all interested scientific, technological and economic entities, but also social ones. In our economic region, we call it Space 4.0. A beautiful idea, but is it possible to implement in such a pure form? The paths of OpenSpace development in different parts of the world have been different from the very beginning and will remain different, and the differences may even deepen significantly. Some space super-regions have excessive ambitions, but do not have the resources to implement them. Or they allocate resources to the implementation of space goals, but not related to the opening of outer space. It cannot be denied that the ideology and technologies of OpenSpace are used to build completely new paths of military domination in outer space. Some super-regions have significant resources and can afford to invest systemically in advance, primarily for the purpose of economic domination, and also in a sense to reserve space and systemic, ideological domination. There will probably be no shortage of outer space, even near the Earth, but it is also about prestige and emotional effects, as well as projection into the future.

The biggest difference between space super-regions is the degree of democratization of the legal and economic activities undertaken. In some, democratization is only a facade term. In others, it is difficult to deny its implementation and existence, but still with certain assumptions. Thanks to the revolution of small satellites, this is an advanced technological and socio-economic revolution on a global scale. The delight at the possibility of placing a cheap small satellite on a functional LEO orbit by a small company with economic satellite ambitions is fully justified. However, economically, a completely different scale will count, large constellations of such satellites. On the side-lines, it should be added that sending such a single satellite by a small company is possible only in strongly democratized space super-regions. Elsewhere, it is rather fiction.

In technological, economic and political environments, and mainly economic and analytical environments, scenarios for the development of the OpenSpace idea are being developed. In Europe, this concerns the idea of Space 4.0 and its collinearity with the Industry 4.0. As already mentioned, in the American super-region, the tone of development is set by chaebols, which can easily strengthen themselves with technologies developed by numerous SMEs operating in the area of space technologies. The above system is heavily co-financed by very numerous venture capital companies, investment angels, etc. In the European super-region, as also mentioned, we do not have such large chaebols or mechanisms for collecting such large funds for joint initiatives with a comparable scope to the American and Chinese ones. However, we have a growing number of innovative SMEs operating in the space sector, which is exactly suited to the assumptions of Space 4.0. The scenarios for implementing Space 4.0 must be different from the American and Chinese ones. The solution seems to be a skilful combination of extensive and intensive development in Europe, equalizing the levels of technology and activating a much larger number of countries. Without creating a broad space front in Europe, we will not be able to compete on a sufficiently massive scale globally.

Poland's situation in Space 4.0 is precisely such that the country must enter the path of intensive development of space technologies. It is necessary to catch up in this region of social and economic development as well. Intensive development cannot be maintained for decades. Intensive development is to lead to the creation of several scientific and innovation centres, training of staff and implementation of own technologies. Then it is necessary to ensure uniform extensive development of space technologies and services on a national scale. In a country of this size and such ambitions, it is necessary to go beyond the vicious circle of buying ready-made solutions. In our Europe dominated by the economies of Germany and France, torn apart by various political and economic interests, can we build a democratic open space above our heads? Other European space leaders, technologically decades ahead of us, such as Italy and Spain, are also going their own way. Does ESA bind us strongly enough into a European whole? But is this its role? Probably not necessarily? We need to develop our own development paths and then implement them persistently.

Is the regional European idea of Space 4.0 also ours? It depends only and exclusively on us. Space 4.0 initiatives must come from both the central and economic and social levels. And we are talking about something much broader and bigger than simple solutions of private-public partnership PPP. Space is something much bigger than just high technologies, business and services, it is related to an Open Space Society. It is a society in which space is ours, economically, politically, culturally. Poland is not yet a space country with only a few kilograms of its own orbital hardware infrastructure. Poland must become a space country to the widest extent possible. Otherwise, we will lose not only the space sector, but many other important issues. Growing to the absolutely necessary many tons of orbital hardware infrastructure will require a great technological, industrial, business and social effort from Poland. It is worth understanding that this is a gigantic effort comparable to the complete reconstruction of the energy sector in the country or a long-term program for the construction of transport, highways, railways, CPK – Central Communication Port, etc. All these sectors have a common denominator in the form of high-tech today, which will turn to ordinary technologies of tomorrow.

But we are not wasting any time in the country in terms of developing the idea of Space 4.0. Something is happening all the time and for quite some time now. The BalticSatApps program accelerates the introduction of services based on access to satellite data to the market [8]. There are more such programs and projects. We participate with our projects in the flagship space programs of the EU. Conferences such as Space 4.0: Solution from the Sky, CTT of the Krakow University of Technology [6] have been organized almost since the declaration of the idea of Space 4.0. There are many more such conferences [7]. However, all this is not enough. These are very important, necessary, contextual activities, creating a positive scientific, economic, economic and social atmosphere around the idea of OpenSpace/Space 4.0. It is still not enough. Other leaders actively conducted such activities some time ago and are still continuing them. We have only just started them. Nothing can replace systemic, high-technology economic activities. For now, we have a good atmosphere to start such intensive activities on a suitably large scale.

The inertia of any large economic activity, and even more so of high-tech, is significant. First, the military must become familiar with space and properly absorb new technologies. European leaders did this quite a long time ago. Then, or perhaps in parallel, it will be the turn of advanced, and then universal, public services. All this takes years, but better late than later. Since 2021, press information about our satellite dreams in the OpenSpace/Space 4.0 system has been intensifying. And already in the years 2023-25 the titles are loudly announcing: Poland has joined the NATO space initiative (Space24), Satellite broadband access in Poland (digital-strategy.ec), Satellite reconnaissance will go to the Polish army (polska-zbrojna.pl), National satellite information system NSIS POLSA (polsa.gov.pl), Polish satellite constellations and their potential (alioth group), Poland is increasing investments in space technologies (bankier.pl), 30 years of satellite television in Poland (wirtualnemedia.pl), Polish satellites will be in orbit in 2026 (poska-zbrojna.pl), Own satellite data (polsa.gov.pl), Poland focuses on space: New initiatives for defence and security (tek.info.pl), and literally hundreds of others.

Due to the high inertia of the construction of orbital infrastructure, let us pose a question and a bold hypothesis in response to such a question. How many tons of efficiently operating, intelligent orbital infrastructure equipped with AI will Poland have in a decade, in June 2035? This is of course related to the pace of the country's development. Can we safely assume that with favorable development it will be a dozen or so tons? For comparison, the current leaders already have more, and in 2035 it can be assumed that it will be hundreds of tons, and in some cases thousands of tons.

V. SPACE 4.0 – STANDARDIZATION AND TECHNOLOGICAL COMMON DENOMINATORS

The strongest common technological denominator of the Space 4.0 idea is small satellites. Why small? The decisive factors were, and still are, the costs and ease of construction, as well as a significant increase in the functionality of almost all components of small satellites. This is somewhat reminiscent of the process of miniaturization and increasing the functionality of personal computers. Since approximately 2012, i.e. a few years before the formulation of the European idea of economic and service liberation of space by the Space 4.0, an accelerating reconstruction, development and consolidation of the global space market has been observed. Entire countries, regions and giga-regions, organizations, and public and private industrial sectors have been involved in this reconstruction, or rather the construction of a new type of the space sector. The opening of space and its use on new principles has become irreversible, protected by global social, economic and political forces. The common denominator of these processes are highly functional small satellites organized into ever larger constellations. A large industry is being built around the powerful idea of small satellites and a new ecosystem of near space development is being created.

From the technological perspective, the construction of the new space sector Space 4.0 is being driven by more and more factors. Some of these factors are directly related to the change in the approach to platform design and functionality of small satellites. The development cycle of a new small satellite is shorter and requires the involvement of fewer expert and technical resources. The decreasing costs of development, testing, production and orbiting satellites are related to these factors and to the miniaturization and standardization of the satellite platforms used. It was miniaturization and standardization that constituted a significant breakthrough in thinking about satellite technology. The significant development of data processing and tele-informatics capabilities resulted in the possibility of placing only slightly more modest functionalities on small platforms compared to large satellites of previous generations. It quickly turned out that small satellites constitute the appropriate infrastructure for building satellite telecommunications systems. Thanks to the GPS system and the fiber optic cable network enabling precise location of system components and ultra-wideband data transmission between them, the ground system supporting small satellites turned out to be much easier to build and operate.

In mass technology, which is what small satellites aspire to in the evolution process, the foundations of success are factors such as rapid prototyping and standardization. In our region, ESA, but also NASA, do not place small satellites in the central place of their large space projects, and mainstream activities. For now, local attempts to standardize small satellites, and with a considerable success, are being led by the industry. Regional industrial associations of small satellites are being established and are actively operating. An example is the Small Satellite Alliance, which promotes the American small satellite industry. In Europe, we are also starting to organize ourselves in this way, building organizations that group scientific, technical, industrial and business communities around the small satellite sector. The growth of economic power, scope of activity and technological competence of such organizations authorizes them to undertake standardization activities in their region and propose such solutions outside. Standardization reduces the costs of individual types of small satellites, increases their reliability, enables interchangeability between manufacturers, facilitates market entry for a much larger number of manufacturers and service providers, and enables the use of open access to hardware and software libraries. Rapid prototyping combined with stepwise standardization is the fast-track development path for new small satellite technologies.

What is, or potentially can be, standardized in small satellites? This is quite a difficult question, because small satellite technology includes materials and their connections, structures and stability, electronics, mechatronics, robotics, drives, optics, sensors, telecommunications, energy and power supply, information processing, on-board computing, reliability issues, safety, and many others. In addition, small satellites form a very large group of devices that differ significantly in dimensions, weight, and functionality. Despite such differences, many common features can be found. Small satellites are most often designed, built, and orbited as components of larger constellations. Orbiting a large number of small satellites is most often done in groups, both to reduce the cost of such an operation, but also due to the convenience of more efficient creation of larger functional fragments of the constellation at once. Payloads of small satellites are standardized, and even such satellites are grouped into types for different payloads. Standardization naturally applies to satellites with identical functionalities.

In various groups of small satellites, the satellite frame is subject to standardization. An example is the long-standing standardized CubeSat frame, as well as, for example, an attempt to standardize the frame for the planned group of Creotech small satellites called HyperSat. A significant degree of structural standardization is demonstrated by satellites forming large constellations and orbited in the USA and China. Small satellites are prepared for orbit in a maximally assembled state. In the case of constellations and group orbiting, small satellites must create a standard payload adapted to the type and conditions imposed by orbital transport. Individual satellites must fit together, take up as little payload space as possible, and allow individual release in appropriate places in orbit. One of the standardization trends for such payloads of many identical small satellites is the construction of a flat frame. Flat frames of small satellites can be more easily packed into larger sets containing a dozen or even several dozen individual units intended for separate orbiting, but in the arrangement of a strictly spatially organized single constellation. The flat frame uses the cargo space of the transporter more efficiently than other frames, e.g. cubic or spherical.

Standardization is progressing very quickly within larger constellations consisting of several dozen, several hundred or even several thousand identical small satellites. Standards used in large constellations are much easier to disseminate between constellations and also between space giga-regions. The era of OpenSpace, and even more so Space 4.0, is only at the beginning of developing standards and starting the process of developing and systematically disseminating Smallsat standards. The process of disseminating standards is one of the important measures of the maturation of small satellite technology within OpenSpace. For now, in the case of some large constellations of small satellites, many technologies are still proprietary. However, such technologies will undoubtedly be systematically released, creating the basis for building international and global standards. In addition to the standardization of the main framework of small satellites, relatively rapid standardization processes are also underway for on-board computers and their software, on-board energy systems and power supply systems, methods of orientation and stabilization of small satellites, general methods of ensuring hardware and software reliability, data transmission and constellation communication, etc. The components of the entire ecosystem of small satellites are undergoing evolutionary standardization.

VI. SPACE 4.0 – CREATION OF SMALLSAT ECOSYSTEMS

What drives the creation of small satellite ecosystems? Some market analyses indicate that the global small satellite market may exceed the value of 100 billion Euro within a decade. Some analyses boldly reach forward five decades, to the year 2070 [10]. In such a time perspective, the role of space in the development of society is visible differently than we commonly perceive it today. Small satellites are to play key roles in these long time perspectives. An inherent characteristic of space is that it is a sensitive area and will never cease to be the center of interest of military techniques. This also means that in addition to civilian, typically business, economic and industrial analyses, the small satellite sector is closely analyzed by the security and defense sector. Both analytical trends of the SmallSat sector - military and civilian, despite different approaches, lead to many common conclusions [11,12]. The SmallSat sector introduces fundamental changes in space, economy, services, security and defense. Some of these changes, in the general layer, are relatively easier to predict. Many details about the finer aspects of the development of the sector remain unknown and are considered as optional, alternative or coexisting development scenarios. However, it also makes sense to consider the development of entire ecosystems of small satellites and not just the evolution of their detailed structure. The detailed structure, functionalities and software will probably adapt immediately to the requirements of the ecosystem. But ecosystems will also change, and there are already examples of their variability, with the advancement of satellite technologies.

The basic factor in the adaptation of small satellites to the developing ecosystems is their functionality. Functionality is generally a non-linear function of the satellite mass, but it seems to have a dominant linear component at the beginning. We do not know this exactly and it is the subject of analysis. The reason is the extraordinary dynamics of the development of small satellite ecosystems. This dynamics is dramatically different in different space-satellite giga-regions. Starlinks from the two American and Chinese giga-regions belong to small satellites and they are definitely dominant in terms of the number of orbited satellites and their aggregated functional mass. Chinese plans to produce currently one and soon two small satellites per day and significantly exceed one hundred collective orbits per year are so massive that they can completely change the global situation. In principle, the only giga-region that can react to these plans is the American giga-region, and rather not NASA, but a somewhat independent giga-region, i.e. the broadly understood American Starlink and private sector ecosystem. Reaction, although probably to a different extent, is also to be expected from the Indian giga-region.

As for the potential response of the European giga-region, there are many doubts in analytical studies. The Space 4.0 region is so heterogeneous in terms of area and so dispersed in terms of local interests that it is currently unable to react dynamically, which seems necessary, and almost immediately. This undoubtedly means a rather difficult situation for our region. The organic and logistical structure of the satellite sector in Europe must be rethought and completely reorganized, if at all possible. An example of the difficulties with such a rapid reorganization in Europe is the confusion and even fear regarding the rapid development of another similar hi-tech sector, i.e. the technology of ultra-high-scale integrated circuits containing ANN, ML, AI DL, GenAI, LLS, etc. components. The barrier of 10 trillion i.e. 10^{13} transistors in a single integrated circuit will probably be overcomed soon. Such possibilities are indicated by the CS-3 and LPU Cerebras systems [22]. In a sense, these two hi-tech areas are twin unicorns, as they will likely determine the global directions of economic development in the coming decades. Adding fuel to the fire in this regard is the recently published US list of restrictions on the export of advanced AI integrated circuits to some EU countries, including Poland. Many different technologies related to small satellites are also covered by the embargo.

As mentioned previously, the psychological and technical development impulse for the OpenSpace idea was given a dozen or so years ago by nanosatellites, mainly the standardized modular CubeSat series weighing 1-10 kg and with the Nx10 cm dimensional standard. They broke many stereotypes regarding the orbital capabilities of small satellites and were a spark that widely ignited the social imagination. In today's technological situation, the role of such pico and nanosatellites has changed. They will remain important, but in the areas of schools, academia, testing, rapid prototyping, and other special services. Small satellites have grown significantly and this is an irreversible trend. The functionality of a satellite for effective use or for sale is related to its mass. One of the many scales of categorization of satellite mass divides them into micro 11-200 kg, mini 201-600 kg, small 601-1200 kg, medium 1201-2500 kg. Why is the categorization of combined mass and functionality so important? The satellite mass is connected with the functionality and cost. With the general increase in satellite functionality, there will be competition between the weight categories of small and medium, but also, surprisingly, large satellites. Pleiades operating from LEO have a commercially available monochrome resolution of about 30 cm obtained from an optical observation system of about 1.5 m. Pleiades Neo S950 VHR have a mass of about 1 ton, so they belong to the category of small satellites according to the above list. The question is: can a satellite of a lighter category, i.e. around 600 kg or lighter, obtain the same resolution of imaging the Earth's surface and the area directly at the surface? We do not have a direct answer to this question, but we can expect technology development in this direction.

This question concerns not only the organization of the ecosystem of small satellites, but the entire ideology of building such coupled technical and service spaces. Let us assume that a light and cheap imaging satellite will consist almost exclusively of appropriate quality and appropriate dimensions of imaging optics, which in practice means a large enough telescope. Let us also assume that the ecosystem is filled with many small, strictly specialized satellites and that ultra-universal satellites are becoming a thing of the past. In other words, a light and cheap observation satellite, i.e. only an appropriately secured flying telescope, equipped with a minimum of other systems, is supported in terms of information and communication directly in the orbit by other small and light satellites from this or another coupled constellation with hybrid functionality. The redundancy of the system of such small satellites in constellations is designed to ensure the replaceability of services, i.e. assure an appropriate level of reliability. We can observe such a development trend of small specialized satellites, where the constellation is responsible for the final functionality, in the OpenSpace area. In addition to the significant functionality of such a system sold as a service, one must add low costs resulting from standardization and specialization, and high reliability resulting also from standardization and redundancy.

There are a number of further questions regarding the potential competition between the above-mentioned categories of satellites. This competition will concern not only imaging satellites but probably all others. In the case of imaging, will the system of specialized constellations operating on LEO and Ultra-LEO with super-resolutions below 10 cm not threaten the dominance of large LEO/MEO and GEO imaging satellites? The immediate answer is very simple - these are completely different categories of satellite devices and systems, used for different purposes. A super-LEO satellite will not image large spaces. But at the same time such a satellite is part of a large constellation that can image a large space together. The detailed answer, especially taking into account the dynamics of development of technologies and services, is more complicated and generally unknown. It is worth remembering that satellite imaging services are currently one of the fastest growing sub-sectors of this market [7]. At some point, it may happen that the cost of the entire highly functional constellation will be lower than a large single advanced satellite, or just a few-element constellation of such satellites, with comparable functionality. The operating characteristics, as well as the ground infrastructure, of such two functionally similar but different in implementation systems will be fundamentally different.

Competition between the categories of small and large satellites will probably concern differential areas. As the technology of small satellites improves, the area of their potential application is expanding, also beyond the capabilities of large satellites. Small satellites not only compete in many areas of classical applications of large satellites, but by entering new areas they significantly expand the capabilities of satellite techniques. In particular, the speed of technology modification, synchronous operation in large, specialized constellations, significant time and space dispersion, time and space dynamics of functionality, continuous, uninterrupted provision of functionality, enable many new methods of data acquisition, transmission and processing.

Such features, combined with the low costs of the entire ecosystem of small satellites, compared to large satellites, allow for taking greater research, experimental, innovative and even economic risks and creating new research methods, areas of services, impossible to take in the case of large satellites. There are fewer and fewer areas where it would not be possible to use small satellites in a highly functional way. It is probably the small, and not at all large, satellites that will massively introduce such techniques as dense, secure, satellite quantum Internet, teleportation and entanglement switching techniques. It is the dense network of satellite telecommunications provided by thousands of small satellites that will add and reveal the true power of terrestrial fiber optic telecommunications. It is the revolution of small satellites that will add a group of subjects related to space economics to university business programs. It is the diverse ecosystems of small satellites that have the chance to rebuild society into an open space community.

VII. OpenSpace/Space 4.0 –Development directions/Scenarios

The OpenSpace/Space 4.0 idea offers real new development opportunities for civilization. Such opportunities are already provided by partially available technology and its relations with the Industry 4.0 idea. Analysis of these opportunities allows for the formulation of bold needs for change. These needs seem obvious, such as ensuring and improving security, closing telecommunications systems with a full, highly effective intelligent satellite layer, expanding and improving health care, improving living conditions, economic, social and cultural development, facilitating international and global cooperation, developing the scientific layer, and many others. Can we base the formulation of these needs on any certainties now? One of these certainties is that LEO orbits will be populated with thousands of small satellites. This process is already underway and the American and Chinese space giga-regions are competing in it.

Europe needs to rebuild the system of observing its territory and surroundings from space using OpenSpace/Space 4.0 technologies. Europe needs to build a secure satellite communication system using OpenSpace/Space4.0 technologies and ideologies. This system must securely serve the banking, health, industry, science and innovation, as well as culture sectors. The system must use the powerful transmission capabilities of new generations of fiber-optic backbone networks. Europe needs to develop many existing and implement new services using space technologies in OpenSpace/Space4.0 technology.

Unfortunately, for now, in none of the above areas can you base your development solely on foreign services. The world is not yet so perfectly organized. It seems that the OpenSpace idea can improve this organization in a favorable direction. This means that in principle each space giga-region will build these layers partly independently and in some opposition to the other regions. Let's hope that in the entire European area we will reach such a good agreement and will not implement such layers individually in individual countries. In the absence of such common solutions in Europe, we are completely lost on the global market. The Space 4.0 ideology is closely adapted to the European area. Even in the American area, its message is different. Not to mention the Chinese area, where it can even be considered naive. We will end our considerations on the OpenSpace/Space 4.0 marriage with an open question. So what chances does our European Space 4.0 have in the OpenSpace area in a hard clash with the American and Chinese space policies?

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