INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2024, VOL. 70, NO. 4, PP. 1031-1041
Manuscript received August 14, 2024; revised October, 2024. doi: 10.24425/ijet.2024.152091

Space 4.0 – a common, democratic European space, part 2

Ryszard S. Romaniuk, Piotr Orleański

***Abstract*—Today we are in a period of explosion of business taking advantage of the new opportunities offered by the new environment of economically open space. The period, sometimes called Space 4.0, is a paradigm shift, with changes in motivation and understanding, actors, and technology. For over a dozen years, under the name NewSpace, a revolution has been taking place in the space sector with the participation of new players, schools and universities, new commercial entrepreneurs and businesses. NewSpace entered the area traditionally occupied by OldSpace - government space agencies and large companies, testing new possibilities. These possibilities include new services, e.g. using data transmission from space, regarding communication, precise navigation, agriculture, surveillance, mapping, geology, climate, space weather, environmental monitoring, and security. The transformation of OldSpace into NewSpace was associated with the business risk of changing old, conservative business models into completely new ones, unknown in this area. The transformation is related to the need to maintain the changes in a reasonable legal system so as not to experience the "Wild West" again, this time in space. It is currently difficult to establish strict rules regarding the still distant colonization of Mars, but undoubtedly establishing rules for the use of the LEO area, i.e. the already crowded low Earth orbits, is becoming an increasingly urgent necessity. In the context of competition and technological cooperation between giga-regions, international cooperation, combating old prejudices and establishing equal opportunities, under the umbrella of social acceptance, we are building in Europe, not without difficulties, a common, democratic space.**

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

I. Introduction

THE development of space technologies, significantly accelerated in the last decade, generates various concepts of systemic development of the area around the Earth, primarily in a functional public, but also private and commercial way. The private space sector is growing rapidly. New concepts of services offered from space generate the development of equipment and full orbital-satellite infrastructures. There is now a new phenomenon of a strong connection between the development of space equipment in the form of small satellites [1], [2] and the demand for the services offered by such equipment. The positive feedback started going both ways here. We are observing the revolution of small satellites, which is turning into a significant economic phenomenon [4]. Small satellites completely change our thinking about space.

II. Opening of Space - the Revolution of Small Satellites

The term NewSpace, coined in the USA in the 1980s [8], referred to the idea of privatization and commercialization of space travel, in particular the so-called space tourism. However, this was related to a different type of equipment, large and intended for the safe transport of people. In some social classes it was even met with some enthusiasm, because it had to be done in the field of private ventures. And they were, and still are, willing to implement such space projects, both large and small. There is demand and adequate supply is being prepared. Construction of the so-called space capsules or manned spacecraft, however, represent a completely different level of finances and technical difficulties, which was recently demonstrated by the problems with Boeing's Starliner capsule moored to the ISS for a long time.

The term NewSpace functions strongly on a global scale in the scientific and economic areas of space technologies. The comparison between NewSpace and Space 4.0 [10] shows some differences between the approach to the economic opening of space in the American and European giga-regions. Yet another approach is being implemented in the Chinese giga-region. Such comparisons also show the state, evolution and dynamics of economic processes in the space sector on a global scale [5], [6]. This perhaps allows us to appreciate what we do and the direction in which we are going in our Space 4.0 area.

We are witnessing the emergence of a large market sector [9]. The terrestrial sector of our civilization and economy has matured to dynamically develop its space branch, also in cultural areas, but also in purely economic, business, industrial, private, PPP partnerships, production, tests of space equipment, research, expansion of orbital infrastructure and increasing the offer of services based on satellite infrastructure. The services offered by small satellites are constantly expanding into areas once reserved for large satellites, such as telecommunications and Earth observations. But they are also developing into areas that have not been offered yet, such as safety, health care, environmental supervision and agricultural support [11], and education [13].

The small satellite revolution is renewing our intentions to colonize the Moon [3], [7] and forcing us to look at the Moon in a different way [12]. The small satellite revolution is reorganizing science, space technologies, the scientific and technical, innovation and business environments. The small

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

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

satellite revolution adds a completely new, and not so small, sector to the economy. An industry of small satellites is being built, different from what has been done so far in space and satellite technologies. Numerous SmallSat conferences are organized [15], [16], [20]. Databases of small satellites [19], and tools supporting the determination of their operating conditions in space [14], and organizations managing the sharing of radio band allocations [18] are being created. There are organizations managing the small satellite sector and ecosystem [17]. A complete new SmallSat ecosystem is being built. The word smallsat is becoming widely used in the economy and in the space sector.

III. Opening of space - how it happened and the current state

Back then, in the 1980s, it was much too early, both technologically and mentally, to formulate the Space 4.0 paradigm. For ESA to make such a decision in 2016, not only the progress of space technologies was necessary, but mainly a deep digital and social transformation of society. A properly developed socio-economic context had to significantly precede political decisions. Altogether, it triggered an avalanche of new activities with space as the main focus. It wasn't governments that graciously agreed to open space. It is not the new Copernicus of our times who said we are opening the cosmos. Quite simply, the time came when we noticed how much we were losing by not using an important part of our property, the environment of existence and operation of our civilization. Then, after realizing our capabilities in space development, it was impossible to stop this process in any way. We had overcome some important stage, and then an avalanche started. We are, without a doubt, a space civilization.

It was necessary for certain key sectors of the economy as a whole to be mature and ready to integrate with the emerging space sector. Space 4.0 may have emerged in some favorable context. This context was then, and still is, access to open space technologies and the ability to scale them in any direction, especially down in size and cost. As it turned out, this downscaling gave a powerful impulse to the development of space technologies. After more than two decades since the birth of the idea of functional picosatellites, or rather nanosatellites, and the last decade of intensive development of their functionality, a reflection comes about the balance between all parameters of such full satellite ecosystems. These parameters, and there are many of them, include: the size of individual satellites, the number of satellites needed in the constellations, maintaining their activity in technical and economic terms, functional details and scalability, automation, etc.

However, the main context for the development of small satellite ecosystems, in addition to the key technical maturity, quickly became a rapid increase in the demand for space services, from large global ones to smaller and increasingly finer and more specialized ones. The names of these socio-economic processes and the attractive slogans associated with them - NewSpace and Space 4.0 - were each created at a slightly different time, in slightly different economic and technological conditions, in slightly different giga-regions. We ask the question, what are these ideologically similar slogans today? Is it cooperation or competition for space services? Can they be named somehow together? Are these processes and their names really global? Do these processes occur equally across giga-regions?

We present the current state of our civilization's orbital assets, in a very selective and approximate way, for the sole purpose of creating a contrasting background for the processes taking place within the NewSpace and Space 4.0 ideas, as close to the truth as possible. In the practical scaling of satellite weights, several categories have been conventionally adopted in the small satellite range: picosatellites approx. 0.1 - 1 kg, nanosatellites 1-10 kg, microsatellites 10-100 kg, super-microsatellites 100-300 kg. In other words, the widely known, iconic, initially educational, and now also commercialized category of CubeSat satellites belongs to the group of nanosatellites or microsatellites depending on the coefficient n at the unit standard U. For example, the CubeSat 6U satellite is a nanosatellite and has dimensions of 10x20x30 cm and weighs on average approx. 7-8kg. CubeSat satellites are built with cheap commercial parts rather than very expensive ones specifically designed for space applications. Potentially, a 1U CubeSat could weigh up to 1 kg and be a picosatellite. However, by default, 1U weighs over 1 kg and is formally a nanosatellite. The original CubeSat standards are, as with all small satellites, subject to technological evolution [5]. Their current advanced and further developing functionalities were unimaginable a quarter of a century ago, when they were created.

To complete the satellite weight scale and show the contrast between their potential functionalities, it is worth providing data on typical large satellites currently in operation in GEO orbits. Large satellites require power from solar panels of several dozen kW or more. Long-operating large satellites must have orientation control systems and an adequate supply of fuel for them. Galaxy telecommunications satellites of the satellite operator Intelsat typically weighed over 3 tons (e.g. Galaxy 35 and 36). The newest Intelsat satellites have grown significantly and weigh approximately 7 tons (e.g. Glaxy 39). Could this opening of space, especially for small satellites, also be the reason for the further growth of large satellites? The weight and size of satellites, and therefore their intelligence, translate into functions and finances.

European third-generation Meteosat satellites, Meteosat MTG, have a similar, although slightly smaller, weight. This weight increased systematically through the generations, e.g. the second-generation Meteosat MSG-11 weighs approximately two tons, and the third-generation Meteosats MTG-S1 and MTG-I2 weighs approximately 4 tons. The meteorological resolution of MTG-S1 is approximately 3 km, and the imaging of meteorological structures is fully 3D. The operator of the Meteosat system is ESA and EUMETSAT (European Organization for the Exploitation of Meteorological Satellites). EUMETSAT also operates the smaller Copernicus Sentinel meteorological satellites operating from heliosynchronous orbits and the second generation Metop MSG satellites operating from polar orbits. There are thousands of such large satellites mentioned above and those of many other operators active in orbit, but this is not the number that is preparing us for the Space 4.0 revolution. In the coming years, tens and perhaps

hundreds of thousands of small satellites will appear in orbit. It is such satellites that will form the core of the Space 4.0 idea.

A large operator of MEO/GEO satellites is the European company SES based in Luxembourg. The next generation of large SES GEO satellites, such as ASTRA 1Q and SES-26, has a completely different character. These are SdS (software defined satellites). We are still quite far from freeing and sharing satellite hardware infrastructure, but SdS satellites are this direction of development. This is a step towards building a network between constellations. Special satellites also fall into the large category. The Hubble Satellite Telescope, operating from a 515 km LEO orbit, currently weighs over 12 tons after four servicing activities. The ISS weighs approximately 420 tons. We pay so much attention to the weight of satellites because its integrated value, a single indicator, proves the degree of cosmicization of our civilization. We have recently known, and this is one of the next signs of the opening of the social space, and the increase in our awareness, that the increase in this weight will in no way depend on large satellites, but on very numerous small satellites.

The argumentation in this process of cosmicization of civilization with the help of small satellites is very strong and at the same time trivial. To carry it out, you need some simple data. Very technologically advanced LEO Starlinks of the second generation, weighing 800 kg, have an assumed lifespan of 5 years and a very high coefficient of intelligence and functional efficiency of their mass. The newest 7-ton GEO Galaxy, with an expected lifespan of 20 years, is equivalent to over 8 Starlinks. We will not go into detail here, but it can be shown that the functional efficiency of a kilogram of mass of 8 Starlinks is potentially greater than that of a kilogram of Galaxy mass. Moreover, in ten years at the most, and certainly in 15 years, the technology of the current Galaxy will be quite outdated. Starlinks will not have time to age during their short lifespan, which is well matched to the pace of development of space technologies. It is also worth adding that the approximate cost of the latest single Galaxy and the workload for its production is approximately the same as for ten, or maybe even a dozen, Starlinks.

Looking into the near future of the development of the space sector in the aspect of the ongoing processes described by NewSpace and Space 4.0 makes it easier and somewhat objective to establish certain reference coordinates that we used above. Perhaps such coordinates are several other main numbers determining the status of our satellite possessions in orbits, apart from those given above. The most beautiful number seems to be the total active orbiting satellite mass. It determines the global functionality of our civilization in space. This mass has recently begun to increase rapidly and is now probably over three million kilograms. Mass alone is not enough. The next global numbers are the cost of putting one kilogram of such active satellite mass into orbit (recently decreasing rapidly), and the information efficiency/agility of one kilogram of active satellite mass (recently increasing rapidly). Studies on the prospects for the development of space technologies provide various threshold estimates for such values.

A significant increase in the profitability of space services is estimated at the cost of LEO orbital launch below 100 Euro per kilogram, and information performance above 1 Tbps per channel per satellite of the current class of first-generation Starlink. This state of affairs is only approximate, as it has recently begun to change dynamically. There are currently several thousand active satellites in various orbits, and the number will soon exceed 20,000. The distribution of these satellites between LEO orbits - small satellites, MEO, GEO - large satellites, is approximately as follows: LEO (500-1000 km) 85% and is growing dynamically, soon it will probably exceed 90%, MEO (5000-15000 km) 3%, GEO (36000 km) 11%. LEO satellites are low-latency in terms of communication and increasingly support a growing number of systems of various layers of the Internet of Things and related CC, IoT and IIoT cloud computing.

The information efficiency of satellite ecosystems, expressed e.g. in Gbps/kg, and in particular the increasing number of small satellites, is one of the most important indicators of the cosmicization of civilization. However, it is a derived indicator because all attributes and functionalities are embedded in the satellite mass. This performance benefits from a standardized allocation of radio spectrum intended for communications with Earth and other satellites. As a reminder, satellites use the natural frequency range from approximately 1 GHz to over 100 GHz, divided into standard bands in GHz: L-1-2, S-2-4, C-4-8, X-8-12, Ku-12-18, K-18-27, Ka-27-40, V>40. Radio channels have been designated within the standard bands for satellite communications. For example, in the L band, these channels are: 1.25-1240 GHz GPS, 1.530-1559, 1625-1.6605. Of course, high-frequency bands are becoming more and more important, allowing for the transmission of larger amounts of information. Generally, in radio channels, the uplink and downlink satellite bands are of equal width. The exception are navigation systems, where the uplink channel is narrower because it is used to transmit only a few control data.

Spectrum allocation is only an allocation of natural resources and in the case of a significant number of small satellites it will not be an exclusive allocation. The information efficiency of the satellite mass depends on the efficiency of the development of this allocated natural resource, using increasingly advanced methods of digitization and signal compression, but also taking into account non-exclusivity. The management of non-exclusive spectrum in the small satellite sector is also structured and formalized. CSSMA (Commercial Smallsat Spectrum Management Association) institutionally helps in this.

In addition to directly converting the bit rate into satellite mass, the basic indicator of the efficiency of the data transmission system is the energy efficiency expressed in the amount of energy necessary to send e.g. 1 GB of information in both directions and related to the satellite mass unit. These parameters and other analogous ones constitute a global parameter that can be called the information intelligence of the satellite mass, which can also be calculated individually for a single satellite or satellite constellation. The technologies involved in increasing the intelligence of the satellite mass come from the integration of materials science and chemistry, electronics and photonics, mechatronics, automation and robotics, telecommunications and ICT. Without a doubt, Space 4.0 has made a dramatic increase in this intelligence during

almost its entire first decade. However, this is just the beginning and further significant increases can be expected in this area. Comparing the advancement of satellite systems currently placed on the most functionally developed small satellites, one can jokingly say that only a quarter of a century ago we sent mainly dark satellite mass into space. That's all we could afford at the time. And yet, sending satellites step by step familiarized us with space and led to the situation we are in today.

The allocation of radio spectrum shared between very large numbers of small satellites is an important systemic issue. It is also related to the emerging problem of bandwidth reservation. Radio communication is required for effective two-way communication between satellites and the Earth. At the same time, communication between satellites is very efficiently carried out using optical methods. The carrier frequency is approximately 300 THz, so there are no problems with bandwidth limitations for photonic communication channels as in the case of radio communications in the GHz bands. Optical communication between the satellite and the Earth is also possible, but most often not continuously and this requires additional architectural solutions of the distributed transmitting/receiving terrestrial system.

In terms of functionality (used to be called missions), satellites are currently divided into five categories: communication, Earth observations, development of space technologies, space navigation, and space science. The communication bandwidth requirements of these different satellites are different, both due to their different distance from Earth and the amount of data generated. Small satellites with masses below 300 kg completely change the situation in the entire space sector, also in terms of the demand for communication channels. More than 80%, and soon more, of the satellites currently serving the communications and space technology development categories belong to this class of small satellites under 300 kg. At the turn of the century, several countries had their own active satellites in orbit. Only a few countries had their own space ecosystems. Currently, over 100 countries have their own active satellites. The last twenty-five years and the small satellite category are changing everything. The large satellite sector will not change as quickly as the small satellite sector is currently undergoing. This statement may also not be entirely true. In such a rapidly changing situation, many predictions may turn out to be incorrect.

An example of potentially rapid changes everywhere, in all satellite sectors, is virtualization. Similarly to the processes taking place in Industry 4.0, the space sector will also be subject to virtualization in the layers of terrestrial and orbital hardware and software. Services offered by space infrastructure will also be virtualized. The entire industrial and service space ecosystem consists of the above-mentioned components plus the rocket, space vehicle and satellite manufacturing sector and the service sector. The full space ecosystem for small satellites is different than for large satellites, in all aspects: production, infrastructure maintenance and services. The main difference is the possibility of creating it from scratch by many countries that do not yet have any major terrestrial and satellite space infrastructures. This is a huge opportunity to develop and disperse the space sector more evenly than before. This concentration of technology centers was, of course, necessary and beneficial in the initial stage of development, but now it seems much more advantageous to disperse the technologies. This dispersion will enable the creation of local ecosystems capable of independently producing and operating small satellites at every stage of their life and maintaining the services offered by such infrastructure.

IV. NewSpace – Space 4.0 – OpenSpace – technologies for opening space – whose credit is it?

The process of the cosmic transformation of our civilization can also be defined slightly differently than it is typically done in the popular media dealing with space, and the alleged merits can be attributed differently. After some regression at the end of the last century, significant changes have been observed in humanity's approach to space since the turn of the century. These changes had been maturing for decades, but such an acceleration as today has not been observed. The long-running intense discussion about returning to the Moon or traveling to Mars has not yet resulted in such great events. However, we notice more and more clearly that space is also our own potential area of business and development, science, innovation and services, culture, also scaled and specialized business, not necessarily just the large one. So Space 4.0 is the result of simply noticing that space is ours and always has been.

These accelerated changes in humanity's view of space are inevitably transformed into political and economic pressure, a change in thinking, and the result is legal changes and the opening of space by existing government administrators. ESA simply referred to these changes and called them Space 4.0, forgetting, perhaps intentionally, about the previously existing name of space commercialization, NewSpace. Without a doubt, the slogan Space 4.0 is very catchy, referring to the already widely popular term and the implemented industry transformation processes Industry 4.0. So in this context, Space 4.0 is due to the global direction of industry development defined by the term Industry 4.0. Space 4.0 is a natural complement to the global direction of development of industry, economy and society.

The term NewSpace is back, but in a different expanded sense, not entirely forgotten from a few decades ago. In fact, NewSpace never disappeared, but evolved into a broader concept of the so-called private space flights, different from public flights organized by government agencies such as NASA, ESA, JAXA. Only recently has it actually acquired this broader meaning with the emergence and legal authorization of private operators developing and managing commercial satellites for communications and geo-observation purposes, developing and operating launch systems and spacecraft for robotic and crewed travel, and providing space-related services, such as orbital transport of crews and goods, conducting research and development activities on space technologies. In this context, Space 4.0 is due to allowing the private and business sector to enter space.

In other words, today the real revolution and the real core of NewSpace are services. This is also what Space 4.0 strives for, and it has such provisions in its directions of action. One thing is certain, we do not have any war over the slogans of open

space. Unless it's tough competition between giga-regions for the services market? Both the ideas of NewSpace and Space 4.0 are mixed to the benefit of the development of the idea of open space. Whose credit is this? Maybe the rapid development of services and competition? As usual, there are many parents of a success. It would be inappropriate to single out one parent here. There is still a long way to success, for now it is only the opening of a long and very complicated road. This path will require many sacrifices from us. We are all mature enough to open this path. For the purposes of these considerations, after presenting some, rather historical, attributes of both terms, let us join them in a friendly way under the common name OpenSpace.

NewSpace, NewCosmos is a somewhat misleading slogan, not to mention that the slogan has become very outdated over the decades, and initially it concerned tourist plans. It is somewhat associated with NewOrder, NewDeal, i.e. political slogans. NewSpace is partly a political and economic slogan. How long can NewSpace be New? Today, with the opening of space for business, it is more and more Big for us and will remain Big forever. So we have, rather more appropriately, BigSpace. Currently, many new technological, economic and social trends influence the development of the entire space sector. So which ones can be considered new? New technologies are constantly emerging and will continue to emerge. The cosmos remains the same, always new? The cosmos is not new, it's just our thinking about it that is changing. Thinking and the development of the economy have changed so much that we called space, not thinking, new. The cosmos will remain so new that from the current perspective of our knowledge we cannot know it in its entirety. But that's not the point here. The task is to effectively, functionally expand our current economy and civilization into the cosmos close to us.

Commercial space today includes numerous start-ups, spin-offs, space-ventures, space-service providers, space enterprises, small satellites, service satellite constellations, small and global internet companies, companies offering turnkey satellite and orbital services, space service integrators, large entities with significant investment opportunities, as well as economic players. The above-mentioned and constantly emerging new innovative and business trends are new, not space, thanks to the opening of space. We have a really Big OpenSpace. Observing the growth of the space market, one can notice symptoms of opening in 2006, mainly in the USA, and a significant acceleration of its development since 2012 [8]. However, this was several years earlier than the first major European initiatives. Since this acceleration, well over $100 billion has been invested in private OpenSpace in the US to date.

In 2016, Europe, which is more conservative and fragmented by borders, named its move towards OpenSpace by a short slogan Space 4.0, referring to and intertwining many initiatives with Industry 4.0. Better late than later. Thanks to this intertwining with Industry 4.0, the slogan Space 4.0 has acquired a global, not only European, meaning. For this reason, one must be careful in what area context Space 4.0 is considered. Moreover, the competition between space giga-regions means that regionally generated ideological and economic slogans do not necessarily automatically transfer to other areas.

The NewSpace initiative undertaken several decades ago was grassroots. The Space 4.0 initiative was formulated in a centralized manner by ESA. That's a big difference. Some areas of business remember this. The business, commercial, private, small and large space in Europe must be not only open but also free from excessive central regulation and management. Overregulation hinders business. In fact, in its documents, ESA disavows itself from being a central, demanding regulator. Quite significant unevenness in the development of space technologies in Europe and even within the European Union means that the European technological periphery responds to ESA, counting on various types of support and possibly help in catching up. This is a big difference from the situation in the USA and the position of NASA. There, NASA simply contracts necessary space technologies or promising directions of development, wherever they appear and become available. In Europe, ESA is building on its traditional hard pillars and selecting new players for easier, non-critical tasks. It is necessary to ask the question whether we are competitive with such a European approach. And how long can this state be maintained?

The attribute of NewSpace is the strong, persuasive word New. An attribute of Space 4.0 is numbering. Both the terms New and Number 4.0 are quite transient attributes. New was used for marketing purposes and was then characteristic of the investment situation by large private entities in the USA. The generation numbering in Space 4.0 was taken from Industry 4.0, but in the literature the fourth generation has been very thoroughly explained and justified even since the beginning of humanity's appetite for space. In other words, NewSpace should also have its generations, somewhat reminiscent of the generation numbering of the MS Windows operating system and mobile phones.

OpenSpace, however, has an interesting Open attribute. Outer space was, is and will always be open. It is not the space that we have opened, but our thinking about the practical economic and social use of its size. And we could only do this once. From this moment on, we have a space forever open to our good actions. This opening of minds did not happen in one day with a great flash of mind. It was a social maturation process. Let's not give anyone credit for this opening, because it's no credit. Such a mini-Copernican merit, economic and service. We cannot assign a date attribute to OpenSpace, e.g. 2006, 2012, 2016, or another, because it would be a distinction of a single momentous thought that opened up completely open space to us. Such a monumental idea has been germinating in human minds since ancient times, and probably earlier, but without any possibility of implementation. We started this more practical opening of space more intensively in the first decades of the 21st century, and it will remain this way forever. Developing commercial and services in LEO/MEO areas will probably take us many decades, and in the meantime, robotic Columbuses will be sent further and further.

OpenSpace, whose credit is it? Beautiful, lofty slogans for opening space are NewSpace and Space 4.0. These are exciting ideas that seem to be easily accessible to everyone: politicians, financiers, businessmen, scientists, innovators, producers,

service providers and all of us service recipients. And of course it is, the idea of a fire spreading rapidly across the entire Earth, or at least on those parts of it that can afford it. Hence, there are only a few giga-regions where the development of OpenSpace technology is possible. It is not so clearly visible yet, but space giga-regions will undoubtedly compete for less industrialized areas in order, among other things, to expand their service offerings. It all seems very simple, economic development, expanding industrialization, competition.

However, space is not a simple development of some new area, with one characteristic and less pleasant feature that it is slightly more difficult to access than the area here on Earth intended for the construction of a new large critical industrial or service zone. It is not only something much larger and slightly more difficult in terms of technology, energy demand, development and population. Whatever we call it OpenSpace, BigSpace, ProfitableSpace or even OurSpace or InfiniteSpace, outer space is one of the most important civilizational and political categories. Funny names and catchy slogans NewSpace, Space X.0, MoonVillage, Moon 4.0 and even SpaceFactory 4.0 are political ideas and slogans whether they like it or not.

An additional, rather ridiculous explanation of the term MoonVillage, or even NewSpace, of the type what the author had in mind, will not help, it is a political idea, even if it is not about the immediate construction of a populated lunar settlement, and before that the organization of orbital trips around the Moon for the richest and unafraid of the risk. Adopting and using a specific slogan means accepting a certain policy generated in a specific giga-region. Such a general and uncontroversial slogan as OpenSpace may be delocalized and perhaps accepted, but after some time. After such a period of time, however, it may turn out to be completely unnecessary, neither politically nor economically. For now, in our European space giga-region we have the beautiful slogan Space 4.0 generated by our space leader and coordinator ESA, accepted and willingly used by space agencies of the countries in our region. At least in our space giga-region, we know well who is responsible for the beautiful slogan Space 4.0, technologically coupled with Industry 4.0, valid for this and probably the next ten years.

V. OpenSpace – MoonVillage – Moon 4.0 – sociological terms and cosmic tabula rasa

One of the important aspects of opening space and its development in the Space 4.0 style is the question of whether to transfer all our political, economic and civilizational problems there. Or maybe it would be possible not to move? Ostensibly, the LunarVillage project, formulated by the former ESA head Jan Worner, is about colonizing the Moon. In fact, it is one of the slogans and open projects strongly associated with the Space 4.0 paradigm. It must be boldly admitted that these ideas of great, prestigious national expeditions to the Moon and Mars, although they still exist somewhere in the consciousness of space policy, and will probably continue to be implemented, have become significantly outdated in today's realities of social development and space technologies. It seems that it would be beneficial to urgently and rationally reformat them, although this is not an easy task, if at all possible.

The direction of development is to open cooperation between giga-regions. The wrong direction is pride, the claim that we deserve primacy, and competition for supposedly important civilization attributes, which one is older, more advanced and stronger. This was the intention to throw the catchy slogan of Moon Village into the social space, counteract it and have our Moon join us. Let's socialize the Moon fairly, democratically, but not by dividing territories between countries and making them only sub-kingdoms of superpowers on Earth with vice-kings in charge, as was once the case in colonial India. Let's not repeat this mistake, it's a terrible anachronism that leads nowhere. The Moon Village slogan was then understood as a lunar colonization project and is currently developing moderately under the Space 4.0 umbrella.

Maybe it was too early to call such an idea (Common Democratic) Moon 4.0? Looking back, today we know that this idea is just Moon 4.0. Are you sure? Is it possible to talk about the Moon from the perspective of space technologies scaled significantly downwards? First, you need to understand more precisely what Space 4.0 means, and it is very simple, and then it becomes clear that the democratization of the Moon is not possible without the Space 4.0 paradigm. Large infrastructures are, of course, BigSpace technology, but then it is only Space 4.0. One can only argue about the proportions of these components. There is no doubt that the paradigm initiated by Space 4.0 and implemented by its subsequent generations will create the majority of local functional infrastructures in space.

The Moon Village is not a project competing with large plans for manned expeditions to the Moon. It is an idea centered around the Moon, promoting a return to its surface, but in a completely different style, concerning the use of the Space 4.0 paradigm to increase and completely open international cooperation in this direction. Moon Village is an idea intended to open and socialize the Moon, bring it closer to us and turn the return to its surface into a success for all of us. This socialization of the Moon is to be real, it is to be a continuous, lasting process rather than a single project and the fact of a one-off return. To paraphrase the song by music group Skaldowie - It's not about catching the Moon, but about chasing it. The point is that the Moon was, is and will always be a powerful motivator of our actions towards space. Another motivator is Mars. Space 4.0 cannot ignore the Moon. It would be like shooting yourself in the foot.

The moon is for some reason still distant, even though it is so close and seems easily accessible. We need to change this understanding, and this is also one of the roles for Space 4.0. And a successful tool may or may not be the MoonVillage. The name of the idea is excellent, although somewhat misleading with this immediate colonization. We have nearby the perfect Moon 4.0 sandbox for our space maturation and the opening not only of civilization, but also of practical training, economic, social and cultural towards space. The moon is like a friendly island in front of the open ocean of space. We are opening it, not today, but very soon for everyone. Suddenly, looking at the Moon today using the Space 4.0 telescope, it turns out that it is much closer than we previously thought. By putting a Moon 4.0 filter on such a telescope, it becomes not only close but also

friendly, also to the private sector.

However, it is necessary to place Space 4.0 and its lunar offshoot Moon 4.0 in appropriate realistic coordinates. These very numerous coordinates, of which we mention only a few, seem to contradict the enthusiasm expressed in the idea of Moon 4.0. The Moon is and will always be a desert unfriendly to inhabitation, in the form in which we think on Earth. It does not have all the easily manageable resources to build larger infrastructure in a simple and quick way. The lack of an atmosphere does not protect against radiation. The polyethylene-plasticized regolith layer must be quite thick to protect us. It does not seem that all technologies that can be tested on the Moon can be directly transferred, e.g. to the BigSpace area, or to other industrial technologies.

The road to Moon 4.0 seems much further than the horizon of Space 4.0, which is why the equivalence and complementarity of the terms MoonVillage and Moon 4.0 may raise controversy in many circles. The idea of MoonVillage naturally seems to be related to the construction of a new generation of a permanently inhabited orbital station around the Earth, but also and above all a habitable orbital station around the Moon. Such a station would be a test platform for life support systems beyond low Earth orbit, as well as a platform and dock for lunar landers. Currently, no such systems exist, so neither Moon Village nor Moon 4.0 are Moon colonization projects, but an extension of the Space 4.0 paradigm with the very valuable idea of open international cooperation.

MoonVillage is a social experiment strengthening the international cooperation. It is a geopolitical, educational and civilizational attempt to prevent the export of the structures of the political division of the Earth to the Moon. MoonVillage, and with it Moon 4.0, is a heroic attempt, a dream of some form of soft ban, if at all possible, or rather a consensus, global agreement not to replicate national interests on the Moon. Moon Village is a kind of, somewhat utopian, form of appealing to our civilization not to repeat the mistakes we made on Earth. Of course, there is always a margin of hope that such an appeal will have some effect. MoonVillage was supposed to be understood this way, but it was understood differently, in a very human way, less ideologically, which was predictable. Have we lost something in this different understanding?

Is it worth persistently explaining the MoonVillage slogan in subsequent scientific articles and adding an even deeper, even more utopian ideology to it? Village is a word that brings to mind the image of idyllic countryside, peace, beautiful weather, growing crops and rather prosperity. None of this exists on our Moon. It is a very difficult environment for potential settlement. And this inevitable settlement, quite soon, for the hardy lunar pioneers who must tread the first functional paths there for many others, for our entire civilization, if we want to move forward. We must become very close friends with the harsh and hostile environment of our Moon. The moon is a great help for us in getting used to space, not an obstacle. That's why the Moon Village we built on the Moon must be beautiful and friendly.

Observing the current differences between giga-regions and their global and space policies, some people consider this idea to be completely utopian. The pronunciation of Moon 4.0, although very close to MoonVillage, is slightly different, because it directly refers in terminology to Space 4.0 and Industry 4.0. This means slightly less emphasis on noble ideologies, more economics and the strongest possible participation of private players in the social transformation of near space, including our Moon. However, this also means focusing more on the European context. MoonVillage is a noble attempt to unite the space world under a common ideology of cooperation. Space 4.0 and Moon 4.0 are paradigms of economic opening to space and reasonable granulation and scaling of tasks so that they become available almost immediately to a much wider group of players, mainly service providers.

VI. OpenSpace – coalescence, integration, formation of the idea of open space

Space 4.0 is a slogan, one of the main slogans of ESA. At the same time, Space 4.0 is a common name for the ongoing economic processes of opening and incorporating space into the economy, with the following evolutionary political, social and other consequences. NewSpace is the big brother of Space 4.0. At the dawn of NewSpace, it was not possible to formulate a program analogous to Space 4.0, but now both ideas are becoming more and more similar. You may need to remember that both terms have different sources, one American and the other European. Both terms function equally actively in specialist literature, but usually separately. Many initiatives started under the banner of NewSpace earlier than under Space 4.0. In the current conditions, both ideas are subject to strong coalescence, and sometimes in a situation without context it is difficult to know exactly which one is meant.

It was not difficult to notice that connecting contemporary technological processes with a common additional cosmic umbrella, slogan, idea is becoming the need of the hour and can immediately be very beneficial, giving technological processes, but also the social processes connected with them, an additional strong development impulse. When introducing the term Space 4.0 into the economic space, ESA listed among these processes the following: digitalization, Internet of Things, automation and miniaturization, advanced production techniques, efficient communication between machines and with humans, universal networking of everything, global Internet covering space, data warehouses and big data technologies, machine learning, artificial intelligence, biotechnologies and service development. Among these expected economic and social processes, we are currently observing the emergence of many new companies connecting economic sectors with space in a direct and indirect way.

We all, including ESA, want the idea of Space 4.0 to mark the beginning of a new period in which space becomes an economic and social area enabling access to knowledge, providing jobs, contributing to economic growth, a place for making decisions, shaping policies, inspiring actions and motivating the next generations. Very lofty goals, but they are the result of opening up and adding space to our economic and social awareness. This opening and joining of the cosmos had to be called something nice. We have taken this initial step, to the best of our current capabilities, and we will carefully reap

the consequences for decades and millennia.

NewSpace currently has a multi-layered structure, similar to Space 4.0. Taking this slogan literally, we have a new, wider access to space, a new space area for new users who have not used it before, a new area of communication, new ideas of inhabiting the Moon and going deeper into space. NewSpace makes us look at space anew, but differently than before. New Space means democratizing access and strengthening the feeling that space is for everyone. It means strengthening the social belief that if someone wants to be part of this initiative, nothing stands in the way of making it happen. It also means strengthening the political belief that nations with innovative capabilities are encouraged to get involved and can become part of this development direction.

From a technical point of view, opening up space means lowering the entry barrier to the space industry. Cheaper access to space is related to several factors such as the use of reusable means of transport, downscaling of orbital transport when advantageous, sharing of transport services and satellite space, development of mini, micro and nanosatellites, operation in low and medium orbits. As a consequence, it is possible to develop and adapt high-quality services, e.g. low-cost data transmission by many operators and other services by many, even small, specialized service providers. This transformation is a very significant and decisive shift in the center of space business from government agencies and public operators to the independent private sector. The private sector absorbs innovations faster and smarter, works in a different motivational rhythm, works at a different, much lower budget level, generally with much higher efficiency. Strengthening the private sector in the space business means the emergence of a public-private partnership almost immediately, and thus filling this sector fully in accordance with the best management models. After some time, mature structures with appropriate business dynamics are created in such an economy sector, which become the driving force for further development.

The recognition of the utilitarian layer of space by society and the economy and, consequently, the political opening of space is a fundamental layer of the NewSpace and Space 4.0 ideas. But that's not enough. Fast signatures of success are necessary for the engine to work. Today there is no problem with this. The space industry has caught on and is starting to be successful. But in the beginning, there was no sudden opening of the magical door to outer space, it was a several-decades-long process of maturing to such an opening. Support for a good early idea whose fortunes are wavering at the beginning often depends on even a small genius idea. Sometimes such ideas fall into the category of crazy, sometimes even arousing laughter and even pity. Some of them, however, experience and even give rise to important directions of technological development. This was the case in 1999, when the CubeSat picosatellite/nanosatellite project was born as part of a collaboration between Stanford Uni and Cal Poly. It is surprising how quickly this idea has become globalized. CubeSat also reached Poland quite quickly. It covered large areas of academic communities, mainly students, around the world. Cube Sat is currently an international collaboration bringing together over 100 institutions, universities, schools, private companies developing nanosatellites and placing various scientific, corporate and even public payloads on them.

VII. OpenSpace – the growth hormone of companies, services and satellites

The CubeSat project, which was joked about at the beginning, has made a dizzying career and is still functioning successfully today. CubeSat is the design standard for nanosatellites with the obvious purpose of reducing costs, shortening development time, increasing satellite accessibility to space, and enabling frequent placement of such satellites with different functions in orbit. The very well-developed and constantly updated CubeSat standard puts university teams and small companies in a dilemma: buy it or make it yourself. If you have a well-equipped, even small mechatronic-electronic-photonics laboratory, you can build such a satellite yourself. The proven model of open industrial electronics standards, such as VME/VXI, defines 1U CS CubeSats weighing up to 1.33 kg, and larger 1.5U, 2U, 3U, 3U+ and nU.

The factors behind the success of the CubeSat standard are undoubtedly the technical layer, ease of production, standardization, low cost, the ability to place any payload on the CubeSat board, the relatively low cost of putting it into orbit, significant interest in the academic and school environment, but not only that. The main success factor was, perhaps predictably, the emerging layer of cheap and universal specialized micro-services offered by nanosatellites. Nano-satellites have become an unexpectedly important platform in the entire orbital transportation and services system. Nano-satellites have undergone a remarkable transformation in recent years from an end product in itself to a platform for satellite services.

The space business noticed this opportunity and the development of small satellites from pico through nano, micro to mini resulted in an incredible growth of this sector of the space market in the form of numerous companies and an increasingly richer service market. The technological specificity of this nanosatellite sector has meant that many of these service companies have developed production and integration capabilities in their own laboratories, keeping production costs at a very low level. The transformation resulted in the creation of many companies integrating marketing and sales of services with the construction and operation of small satellites. High competition in this sector of the space market causes such companies to rigorously maintain very high cost efficiency. No one doubts that this sector of the space industry is one of the strongest pillars of the idea of open space NewSpace and Space 4.0, i.e. OpenSpace. Cosmos tastes best in the SME area if you can taste it with a small spoon.

OpenSpace, not only ideologically, but by targeting interest, demand and funding streams, has generated a clear trend of increasing the size of SMEs operating in the sector, but also the associated increase in the average size of satellites and the expansion of their functionality by adapting to current needs. A praiseworthy example in Poland is the activities of the rapidly growing Creotech company specializing in the hi-tech, satellite technologies and quantum computing sectors. For now, domestic companies, growing like mushrooms after rain, are trying to build small satellites, well below the contractual limit

of 1,200 kg. If the OpenSpace idea also works in our country, this size will increase as the demand for complex satellite functionalities develops. Nano-satellites gave an impetus to the development of the OpenSpace idea. OpenSpace has enriched and developed the family of small satellites. Small satellites have caused a revolution in space technologies and available satellite services.

A very interesting and encouraging example of such a possibly emerging group of educational services and supporting educational, institutional and commercial innovations related to small satellites is the action of the Spanish satellite company PLD Space announced in July 2024. The campaign called MIURA 5 Spark concerns five missions to place a constellation of many small satellites in LEO orbit at the turn of 2025/26. The first two missions are described as demonstrations of satellite deployment techniques and are open free of charge on a competitive basis to interested companies and institutions that can submit their small satellites for orbit. The MIURA 5 Spark project is supported by the Spanish Ministry of Science, Innovation and Universities, the Spanish Space Agency, several other Spanish scientific and regional institutions, and on the part of ESA by the Spanish office of the educational division ESERO Spain [13]. The regulations and progress of the project can be monitored on a dedicated website. PLD Space is a Spanish company developing the technology of partially recoverable Miura 1 and Miura 5 rockets, capable of carrying small satellites with a total weight of up to approx. 500 km to various LEO orbits, including helio-synchronous ones at an altitude of 500 km. Without a doubt, the unprecedented action of the commercial company PLD Space supported by public funds is an excellent example of the idea of OpenSpace and Space 4.0. Let's hope for a similar approach to practical, effective publicity of space also by other companies and other similar actions.

The unique attributes of small satellites, compared to large OldSpace-class satellites, are completely changing space and satellite engineering. These are typically structures weighing less than 1,200 kg, although this definition varies in different environments. They literally open up the cosmos very wide for many new teaching, scientific, testing, innovative, commercial, sectoral, social and many other initiatives. The annual Small Satellite conference, this year traditionally organized in Logan, UT, USA on the campus of Utah State University on August 3-8, is the 38th in a row, and is starting to gather more and more participants. The SmallSat conference was initiated in 1987 as an academic meeting. Currently, it gathers over 5,000 participants from over 50 countries. In this small satellite development environment, structures weighing no more than 250 kg are considered small. So, for now, this overall increase in the dimensions of small satellites must be approached with caution. There is no doubt that the increase in demand for functionality and services will also be related to the increase in the dimensions of small satellites. The world's most important scientific, technical and innovative conference, SmallSat, combined with a technical exhibition, is currently exploring the issues of advanced automation integrated into the entire ecosystem of small satellites, including: space, orbiting, ground stations, and the user layer. The SmallSat eco-system is to be effective, intelligent, modular, multifunctional and scalable.

VIII. OpenSpace - SmallSat eco-systems in the Space 4.0 program

The enormous interest in small satellites is reflected in thwe cientific, technical and business conferences accompanied by exhibitions of space equipment. A European technical and business conference on SmallSat Europe, dedicated to SmallSat ecosystems and the issues mentioned above, is planned in Amsterdam in May 2025. In November 2024, the SmallSats conference was held in Bremen during the Space Tech Expo. The annual Small Satellite conference has been hosted by Utah State University at Logan for 38 years. This year's edition was traditionally held in August 2024. Silicon Valley, the birthplace of CubeSats, is the organizer of the SmallSat Symposium, the 2024 edition of which took place in Mountain View in February this year. ESA is the organizer of the 4S – Small Satellites Systems and Services Symposium. The 2024 edition took place in May in Majorca. The small satellite community is organized in several scientific-technical and industrial-business organizations. For example, the SmallSat Alliance is an organization that promotes the U.S. small satellite industry.

Building a full ecosystem for small satellites seems to be a very complex issue. Conventionally, counting the beginning of the social and economic opening of space in Europe from the popularization of the idea of Space 4.0, however, it turns out to be too short a period of time for countries that previously, for various reasons, did not have any larger space infrastructures and active satellites and experience in managing them to build such an independent ecosystem. However, if we take a closer look at currently available technologies and all components of the SmallSat ecosystem, this issue is equivalent to building a new turnkey economic sector. The definition of small satellite includes categories of both nanosatellites and microsatellites, or super-microsatellites for which the required ecosystem may vary in terms of the size of the required infrastructure and financial outlays. In other words, building even a full ecosystem for small satellites is nothing special.

Europe, under the banner of Space 4.0, seems to be facing such a challenge of building a distributed, rather than centralized, SmallSat ecosystem. Why scattered? The ecosystem and construction of large satellites in Europe is quite centralized. Building ecosystems for small satellites in countries that are able to develop such an economic sector addresses their space ambitions in the best possible way. Additional centralization of all space ecosystems in Europe will not bring anything good. This is against the idea of Space 4.0. However, the situation is not that simple, you have to take into account the activities and pressure as well as competition in the area of small satellites from other giga-regions, as well as from your own large industry. Europe will soon, perhaps, be faced with the need to build large European constellations of small satellites with a number of tens of thousands of units. It is clear that strong competition between giga-regions for physical and radio space in LEO is beginning. Hundreds and soon thousands of small satellites currently being sent by competing giga-regions permanently reserve such spaces.

Thousands of small satellites and the full infrastructure for

them cannot be built in the SME sector. This is an issue for large, fully automated industry, producing both satellites and rockets that launch them into orbit in a serial manner, from quickly prototyped modules, with functionalities that change effectively at the pace of technology development. The issue of building a SmallSat ecosystem in our giga-region is, as you can see, a very complex problem. First, it must address the ambitions of individual countries, such as Poland and economically similar ones. Secondly, it must keep up with global development trends so as not to irrevocably lose the opportunity to build its own economic sector.

Let us list a few selected issues that are key to building the SmallSat ecosystem. There are many such issues, some of them are: connectivity and ensuring adequate bandwidth for broadband digital transmission, ensuring the orientation of a small satellite, automating functions, optimizing the ground infrastructure for hundreds of thousands of small satellites, disposal of small satellites after their lifetime, etc. Radio spectrum allocation in terms of technology and standards has been extended to space using methods used for terrestrial communications. The radio space can be considered ordered. However, please remember that all resources are limited, including the radio spectrum. With increasing bandwidth served by single satellites and an increasing number of satellites in some orbital regions, the bandwidth may become less available. SmallSat ecosystems must be radio licensed in the areas where their services are offered.

An ecosystem supporting thousands of small satellites must be responsible for their entire relatively short lifespan. All satellites are maintenance-free, both large and small. Large satellites are required to be equipped with attitude control propulsion systems and fuel. A significant part of small satellites will belong to the micro and super-micro groups. This group is also equipped with orientation systems and impulse micro-engines with fuel. With tens of thousands, and soon hundreds of thousands, of small satellites, the maintenance ecosystem must ensure certain environmental protection conditions also in space. Green space fuels are oxygen and hydrogen. The most commonly used highly toxic fuel is hydrazine, due to its very high energy density. For this sector, which also includes nanosatellites, also in the CubeSat standard, separate green chemical micro-propulsion systems are being developed. Virtually all large and smaller companies involved in building the small satellite economic ecosystem are working on automation, low-energy satellite orientation, microengines and fuels. Many such lines of work can be mentioned here. For example, in the area of chemical fuels, single-component solutions with an energy density much higher than hydrazine, which is taken as a reference, are sought. Many companies have their own full solutions for small satellites, i.e. engines, automation, fuel, e.g. JPL, EPSS/NanoAvionics, and others. For small satellites, depending on their size and technological progress, orientation drives that are not chemical, but e.g. electric, are also promising.

Building an ecosystem of small satellites cannot avoid broader problems such as the sustainable development of this new, rapidly growing sector, including development prospects, the durability of the small satellite sector, new areas of application, problems related to their large number, avoiding potential collisions and their disposal after their lifetime as waste. spacecraft. With hundreds of satellites this is not a problem, but with hundreds of thousands it becomes a systemic issue and an important part of the small satellite ecosystem. Satellites in such an ecosystem must take these factors into account in their design. They must be able to avoid collisions to a certain extent, which means they must have additional demanding functionality - situational awareness and fast on-board automation.

Small satellites in a large ecosystem must also be able to deorbit, also automatically, or be placed in a junk orbit after their lifetime. Currently, putting a small satellite into a junk orbit is unlikely because it is located about 300 km above the GEO orbit. It is energetically economical to decelerate a small satellite, deorbit it and burn it up in the upper atmosphere. However, if hundreds of thousands of small satellites turn into millions, the problem of toxic satellite combustion in the atmosphere will become non-trivial. If small satellites continue to grow, deorbitation must be controlled into the uninhabited area of the South Pacific east of New Zealand. With the large number of small satellites, tens of thousands of deorbitations annually into this region will likely spark environmental protests.

Situational awareness, the possibility of complex diagnostics of one's own state, resources, remaining life potential, threats, the potential to maintain a critical level of functionality, autonomous critical decision-making, etc., these are the components of the on-board intelligence with which we will have to equip small satellites if there are really many of them. We must be aware of what is involved in building numerous ecosystems for small satellites. And we already know that the construction of such infrastructures for hundreds of thousands of small satellites is now unavoidable. The great race for small satellites has started and is unstoppable. It will decide the dynamics and directions of development of OpenSpace, but also other space sectors.

REFERENCES

[1] A. S. K. Pang, B. Twiggs, 2011, Citizen satellites, Scientific American, 304(2), 48-53
[2] J. Puig-Suari et al, 2016, Small satellite standardization: lessons learned from the CubeSat revolution, Proc. Internat. Astronomical Congress, IAC
[3] J. Wörner, 2016, Moon Village: a vision for global cooperation and Space 4.0. ESA, https://blogs.esa.int/janwoerner/2016/11/23/moon-village/
[4] B. Lal, et al, 2017, Global trends in small satellites, IDA STPI, Washington DC, Technical report P-8638
[5] A. Johnstone et al, 2018, Updating the CubeSat standard to keep pace with the growing industry, Proc. Internat. Astronomical Congress, IAC
[6] J. R. Behrens, B.Lal, 2019, Exploring trends in the global small satellite ecosystem, New Space, 7(3), https://doi.org/10.1089/space.2018.0017
[7] H. K. Athanasopoulos, 2019, The Moon Village and Space 4.0: The open concept as a new way of doing space?, Space Policy 49(8), 101323, https://doi.org/10.1016/j.spacepol.2019.05.001

[8] G. Denis, et al, 2020, From new space to big space: how commercial space dream is becoming a reality, Acta Astronautica 166, 431-443, https://doi.org/10.1016/j.actaastro.2019.08.031

[9] G. S. Aglietti, 2020, Current challenges and opportunities for space technologies, Frontiers in Space Technologies, https://doi.org/10.3389/frspt.2020.00001

[10] W. Russo, 2021, New Space and Space 4.0, https://union.eng.br/wp-content/uploads/2021/04/NEW_SPACE_AND_SPACE_4_0_v2.pdf

[11] D. J. Curnick, et al., 2022, SmallSats: a new technological frontier in ecology and conservation, Remote Sensing in Ecology and Conservation, 8(2), 139-150, https://doi.org/10.1002/rse2.239

[12] Y. Akisheva et al., 2024, Regolith-based lunar habitats: an engineering approach to radiation shielding, Springer, https://doi.org/10.1007/s12567-024-00540-4

[13] PLD Space, 2024, MIURA 4 Spark programme https://spark-program.pldspace.com/en/

[14] ESA SPENVIS, 2024, Space Environment Information System https://spenvis.oma.be/intro.php

[15] Small Satellite Conference, 2024 https://smallsat.org/

[16] SmallSat Europe, 2024 https://2025.smallsateurope.com/

[17] SmallSat Alliance, 2024 https://smallsatalliance.org/

[18] CSSMA Commercial Smallsat Spectrum Management Alliance, 2024, https://www.cssma.space/

[19] Nanosats Database, 2024 https://www.nanosats.eu/

[20] SmallSat Symposium, 2024 https://smallsatshow.com/