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Paragraphs for Space Shoggoths, Bush robots, and Dyson Trees – the legal complexity of manufacturing space objects using natural and artificial space resources

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1. INTRODUCTION

Planning a space mission is mostly constrained by factors of payload mass and volume, as well as the efficiency of systems and launch capabilities of a provider. Nearly all contemporary satellites carry a limited number of spare fuel for maneuvering and station keeping, no spare parts, not even means to provide proper repairs. The future of space mission architecture is dependent on both, the interconnectedness of its elements as well as sustainability and optimized logistics. This calls for more operations requiring robots as servicers, factories, constructors resource extractors, and power providers. It is very easy to simply dismiss the concept of ISRU (In-situ Space Resource Utilization)[1], OSAM (On-orbit Servicing, Assembly and Manufacturing)[2] and Recycling/Upcycling in space by declaring the low tech readiness level of required technologies, or that they have been discussed in the years between 1960-1990, causing controversy in both scholarly fields as well as within space policy itself. It should be noted, that visions of space progress driven by vast industrialization and extraction/processing/manufacturing capacities were the reason that the L5-Society[3], The National Space Institute, AIAA and others have advocated for the rejection of the Moon Agreement of 1979[4]. Similarly, we can see a gradual shift in discussing space resource utilization rights, which have recently gained more and more traction due to national developments of The United States, Luxembourg, or the United Arab Emirates, to discuss the problems, and issues involving space products and objects partially of fully composed of space resources. The scope of this paper is to discuss the impact of the ability of space objects, whether one or a group of them, being able to construct other space resources using either natural resources extracted from a celestial body, and outer space, or reusing elements of space debris or wreckage.

The title uses the terms like a "shoggoth"[5] or bush robot[6], which in this paper are interchangeable concepts of modular, reconfigurable robotic space objects capable of extracting resources, materials processing, constructing components, elements or whole new space objects, including its copy, in the sense similar to Moore's Artificial living plants[7], or von Neumann's universal kinematic assembler[8]. Although being inspired by science fiction literature and futurology, there have been many

academic approaches or even demonstrations of either partly self-replicable hylotechnological[9] machines, or modular robots, even forms of so-called "utility fog". The concept of Dyson Tree[10, 11] is being brought to bridge the legal gap between biological and hylotechnological solutions, as well as to present a different approach to what actual ISRU might look like.

This paper will mostly focus on the field of space law as it is relevant to identify problems arising from space objects being manufactured in outer space and out of space resources, although it will address some aspects of patent law.

2. SPACE RESOURCES – WHAT DOES THE TERM MEAN?

While the majority of works on space resources tend to focus on the interpretation of Article II of the Outer Space Treaty (OST) or convincing its peers that the Moon Agreement still has a chance, not much is being discussed in the terms of what exactly constitutes a space resource. For example, the US Space Launch Competitiveness Act of 2015 defined them as "abiotic resources, including water and minerals", while the UAE space act defines "any non-living resources present in outer space, including minerals and water". While they overlap in mentioning minerals and water as being included in the term "resource", they use different concepts for possible resources of biological origin. The term Abiotic means that such resources cannot be a living organism, nor its "biotic" products, such as proteins, organic gases including methane or their fossils, while the term non-living only excludes actual organisms, not their fossilized or sedimented remains, nor their products. To use a parallel from Frank Herbert's "Dune"[12], while a UAE licensed operator cannot harvest or isolate a sandworm (a living organism), it can collect the spice (the biotic product), while the American operator can do neither, though this does not prohibit them from mining moisture (water). Although this is also up to reconsideration, even terrestrial oxygen in its current amounts should fall under the concept of a "biotic resource".

However, the idea of a space resource, while mostly connected to celestial bodies is dependent on the understanding of what this resource is, and on the other hand, by the old concept of space mining. While space mining has been a staple of futurism and science fiction since the late XIXth Century[13], the idea of mining and the analogies to terrestrial history and practices sometimes hinders the discussion and understanding of what actually would constitute such operations. That is not to say, that there won't be any industrial-scale resource extraction on the surface or atmosphere of celestial bodies. However, the majority of approaches focuses on space mining only in the context of monetary benefit[14] of importing extracted platinum group metals or rare earths, in some cases even Helium 3. What is mostly missing from this discussion is the versatility of resources and their applications. What constitutes a resource is what we can obtain on sight and whether we have any use for it. While works on space mining mostly focus on minerals and water, works on ISRU tend to take a broader approach which changes the definition of a resource.

The ITU declares orbits as natural resources[15], and in some cases, the terms get intertwined or put into one category with solar radiation, temperature gradients and microgravity of outer space[16]. While these do not qualify as space resources per se, there is a case to be made for profitable use of such "resources", as we used them explicitly for numerous types of commercial satellites and scientific crewed space

programs. Albeit treating the phenomena of the environment as a resource, which is also worth noting for mission planning purposes, the majority of space resource utilization activities will revolve around some forms of raw materials or unprocessed compounds. Be it regolith, hydrogen, different types of gas and ice (collectively known as volatiles), different metals or organic compounds, it all boils down to what a given operation requires. One person's worthless lunar dust is another person's basic construction material[17]. Besides that, there are also resources to be found in a planet's van Allen belts, as well as in the solar wind or interstellar medium. The same Helium 3 can be easily found within the solar wind, as it is the primary source of lunar helium deposits, though activities on these two sources of a resource might be regulated differently. One is floating through the solar system on the solar wind, the other is a rich deposit implanted in the lunar, or mercurial regolith. The main discourse in international space law revolves not around resources from the planetary atmosphere, solar wind, or interstellar medium, but on these which are embedded in celestial bodies. While space law does not differentiate between celestial bodies, treating cloud moons and synestias the same way as the moon or asteroids, although the American space resource law defines an asteroid resource as a form of space resource found in an asteroid, yet the law was being written with the special interest of asteroid miners in mind. While it is difficult to argue, that using a Matloff[18] or Bussard scoop[19] to harvest the ISM or solar wind differs from catching and processing an asteroid, which then differs from mining operations on planetary and larger, geodal satellite bodies, present-day discussions on space law tend to not see the difference or even recognize the existence of other types of resource operations than mining and importing heavy metals from the Moon and Near Earth Asteroids. Focusing on importing metals and minerals down to Earth misses the crucial elements of space resource utilization, mainly survival and growth.

3. WHY THE BROADER APPROACH?

A broader approach to space resources is required to understand, that any entity looking to utilize mineral or mineraloid resources of celestial bodies to build and maintain its economic or habitual presence will not be making it out of platinum, gold, thorium, or promethium. The majority of them will have to be created using better suiting material, available in an unrefined or unprocessed form on celestial bodies. This has to be included in any discussions centering on a so-called benefit sharing principle, or proposals to declare natural resources of celestial bodies "Common Heritage of Mankind/Humankind"[20]. Since manufacturing space objects out of space resources, and providing them to governmental, commercial, or academic entities, not mentioning a variety of NGOs falls neither under bringing said resources down the terrestrial gravity well, neither it is considered "use for support of one's (scientific) mission"[21] it either hangs in a legal void, or rather vacuum, or tends to be an overstretch of the later concept. ISRU activities, which by their name don't necessarily carry an industrial or commercial element to them, can't be clearly separated from using the same means and tools, such as processing water ice for LOX/H2 fuel, of which some amounts may be sold to other space actors. In the same way, a robotic "spacedock", used to service space objects and utilizing natural space resources cannot be treated the same way as asteroid miners reentering with ores or scientific missions producing oxygen, fuel, or shelter from regolith for their own

needs. To which point a space object is allowed to use space resources under such a regime? Merely repair or also reconstruction? Producing additional copies or programmed subunits? The answer is, that the CHM/H regime doesn't fit the modern approach to space resources, and rather creates more obstacles while providing little to no benefits to any participant or beneficiary of space resource operations. It is not to say, that nations and international organizations cannot set fees or tax levies on the import of space-produced goods, or even employ space miners and manufacturers as contractors to their endeavors, paying them only for the work provided and keeping all resources to themselves. While there is a need to set up rules for space industrialization, to provide safety, sustainability and clarity, these rules need to take into account that *currently* valuable metals (which might face a similar fate to aluminum) are only part of what constitutes a space resource. Furthermore, the ability to produce space objects and equipment on-site using various methods and processes, even on an industrial scale, even though they might use REEs and PGMs in their subsystems should not qualify as a basis for monetary benefit-sharing, due to the sheer problem of how such mechanism would be implemented for space-to-space services.

3. SPACE MANUFACTURING, SELF-REPLICATION, AND WRECK CANNIBALIZATION – HOW DOES THE JURISDICTION WORK?

One of the crucial questions of space manufacturing, especially using space resources is how does one's jurisdiction work when the object launched from Earth produces and assembles other space objects and their components. While article VIII of the OST addresses objects launched and assembled, the main notion is that they have been produced on Earth using natural Terrestrial resources. While it is true that nations retain jurisdiction and control over space objects that are within their registry or control, similarly to seafaring vessels and aircraft. Contrary to what some might think of them, space objects, regardless of the size, purpose, and presence, are considered to be mobile jurisdictions under. In this sense, they only extend jurisdiction, control, the rule of law of their respective countries within their boundaries. It seems to be more of a legal fiction when considering an artificial habitat placed within a repurposed lunar lava tube, yet space law explicitly prohibits any form of homesteading or extending territorial sovereignty to the land where a habitat has been placed, even above or below ground. Thus basically it is assumed, that all of them are in motion, whether propelled artificially or in celestial relation to Earth. While there is still controversy around industrial mining operations in outer space, the more problematic concept is creating new space objects in-situ.

First of all, we need to answer the question, whether or not an object produced using space resources would be even considered a "space object" as it is used in the framework of international space law. International space law does not define space objects beyond what the Liability convention and Registration convention consider as a space object or its components. It is however not difficult to realize, that these regulations were made even prior to the Shuttle era, and most space objects their components were supposed to be launched from Earth and into outer space or landed on the surface of a celestial body, where they would be assembled

into final space objects, such as modular space stations. Yet we could assume that a space object manufactured in outer space inherits the jurisdiction and is added to the same registry as its "mother object". The alternative is to declare such objects void of jurisdiction, control, and beyond anyone's possession, or under the control of the United Nations, representing humanity as a whole. While it might seem even reasonable for projects that have been commissioned as "internationals" and have specially tailored legal frameworks prepared for the transnational or supranational jurisdiction and control, this cannot be the case for national or private commercial ISRU/OSAM enterprises. Thus the author proposes the von Neumann Doctrine.

5. THE VON NEUMANN DOCTRINE

The source of upcoming problems with space manufacturing in space law is the new form of a space object – an object able to create other objects on demand. It is not to be viewed only as a self-replicating machine[22], rather a factory using space resources to produce space objects in the form of construction parts, spare parts, processed and refined resources[23]. Will tools, space suits, consumables, spares, or articles of manufacture count as space objects and require a registry?

Those that are launched from Earth certainly do. The problem with registering space objects and their components is engrained in the state practice. Some states do register space suits, supplies, etc, others don't register even CubeSats. And even worse, some operators don't register on-board populations Tardigrades[24]. The problem here lacks precedent. Although 3D printers[25] and in-space extruders[26] have been flown on board of the ISS, there still hasn't been a single case of registering an object printed in orbit, during flight or on a celestial body. States or their nationals might choose not to register tools and spare parts that have been produced experimentally. However, that becomes a tougher case when space manufactured objects become bigger and more mobile. Space objects that are produced commercially or even en masse are going to be shipped to external customers at some point. Furthermore, retaining jurisdiction over a space object created from space resources, such as a new habitat or a factory provides an extension of one's power into outer space. In the case where space manufactured objects fall outside of the category of space objects, states neither take responsibility nor claim ownership of such products. This has been addressed by the Moon Agreement and was one of the more positive provisions of the failed space treaty. MA's article 12 recalls the language articles IV and XII of the OST and provides that states do retain jurisdiction control over their personnel, vehicles, equipment, facilities, stations, and installations on the moon. Thus not only do vehicles, and stations, but also other facilities and equipment are regarded as under the jurisdiction and control of a state party. As also article 8 of the MA clarifies, that stations might be placed underground or moved, the concept of using civil engineering and burrowing methods was of concern to the legislators.

Here however we reach the problem of objects creating objects. One might call it a registry explosion, where suddenly a state placing a mobile robotic facility on a celestial body may approach the UNSG with notification, that it has registered a hundred sheets of invar steel or several dozen struts and beams of cemented regolith or foamed/honeycomb structures, which at this time are to be viewed as

a component for that state national's station-facility or are an export product to be sold to a foreign entity. In this case, objects creating more objects pose a problem for the old system of registries, for the equipment they produce may be shipped to other stations "on the fly" and consumed the same way, as it is with lean manufacturing models. It should be reasonable to rethink the whole model of registry in international space law, for more orbital and deep space traffic, more "sustainable" models of space missions employing ISRU and servicing will lead to objects creating new objects[27]. Those might not be the famous Von Neumann machines[28], yet self-replication, repairing, or reconstruction might mean a set of different things. The idea of Self-replicating growing lunar factories[29] was proposed during the times of the New Space Program[30]. Even if this concept seems farfetched or belonging to a work of fiction, currently there are several studies on nano-assemblers or xenobiological[31] inventions that blur the line between "organism" and "machine" and pose some forms of self-replication[32]. Following this concept, we can assume that the entity that controls the space factory is also the entity that controls and retains jurisdiction of all those objects manufactured in outer space, for jurisdiction is not affected by that object's presence in outer space or on a celestial body (Article VIII). Thus, although there is a problem with the academic consensus on the grounds of appropriation and use of space resources, the US law ``Sec. 51303. Asteroid resource and space resource rights" states that US citizens are entitled to own, possess, transport, use, and sale asteroid, and space resources. Therefore a facility under a US jurisdiction starts obtaining space resources to create space products. Thus those would undoubtedly inherit manufacturers jurisdiction. Yet even if there was a form of a Von Neumann Doctrine, regarding the inheriting of the jurisdiction of the manufacturing object by the object it had manufactured or constructed[33], we can face similar problems as satellite registries do[34]. Those problems stand from the problems with on-orbit transfers or lack of proper registries among space faring nations.

Therefore, in a scenario, where State Party 1's national produces generic space stations out of space resources and provides them with basic equipment for life support, station keeping equipment, transponders, shielding, and so forth. State Party 2's nationals purchase this generic station for its own needs. The basic question of jurisdiction here comes in the issue of ownership of a manufactured object after it has been sold to a foreign entity. First, it all depends on the export control regulations of State Party 1. A space station or elements of thereof might contain strategic technology and as such are subject to regulations of acts such as the USA's ITAR[35] and EAR[36] apply to selling parts and know-how or transferring technology to foreign entities[37], such as star trackers, atomic clocks, control moment gyroscopes, thrusters of specified parameters[38]. Thus, selling such objects and handing over control and registry shall count as the export of a good to a foreign entity. Any form, be it shipment or transmission of a dual-use technology (manufactured or in form of blueprints or 3D-printer file formats) is regarded as a form of export[39]. However, it is not clear if or which of space manufactured goods will be covered under the provisions of ITAR and EAR. Shall sheets of metal alloy for base or spacecraft construction fall under such provisions, then any form of Station-to-Station trade should be consulted with the proper federal authorities. In the case where State Party I doesn't cover such technology under export control, the transaction needs to involve the transfer of registration and control to the emptor.

There is also the issue of patent law, concerning such quasiterritorial acquisition. Patents as a territorial right are guarded by the law of the entity retaining jurisdiction over its objects in space. United States law 35 USC § 105, states that any invention that has been made, used, or sold in outer space on a space object or component of thereof that is under the control or jurisdiction. The law however provides a handful of exceptions that might provide sufficient ground for avoiding infringement lawsuits on the basis, that a State (The United States in this case) lacks jurisdiction over the space object where an invention is used or sold or made[40]. It is also the question of sufficient control over a space object that would suffice for the US entity to claim that an object is under US jurisdiction.

But if State Party 1 doesn't have such strict export control or the enforcement of patent rights is negligible, then State Party 2 might find itself in a situation, where it might re-register the object to its jurisdiction (might be even an obligation in some future) or simply remain the operator of such generic space station that would remain under the jurisdiction of State party 1. In both cases, this might constitute patent infringement in the form of unauthorized use or import of inventions that are patented in SP2's jurisdiction. According to the US court practice, there are instances of extraterritorial applications of patent jurisdiction in the cases where the infringement takes place, yet there is also the memorable case of Hughes Aircraft Co. According to the findings in this case ruling[41], sending data and telemetry does not constitute control over a space object for purpose of patent litigation. Thus the only concept that remains is the Floating space islands and flags of convenience doctrines. In the case where SP2 has registered a new object, thus turning its control and jurisdiction over to its state of nationality, the buyers of the space stations shall be deemed liable for infringement on the rights of the patentee. The only way that the patentee may secure their rights in those situations is by using the priority mechanism of the Paris Convention and apply for patents in numerous jurisdictions creating patent families.

Here however we may also take into account the idea of temporary presence. A passage of a spacecraft containing patented cargo or a "way station" being used to transport the products further might be deemed a temporary presence. The US code provides such provisions for space vehicles, referring to them as "an object intended for launch, launched or assembled in outer space, including the Space Shuttle and other components of a space transportation system, together with related equipment, devices, components and parts"[42].

The von Neumann doctrine could be found useful especially in the context of space-bound factories or objects possessing manufacturing capabilities and especially self-replicating technologies[43]. Extending jurisdiction on the produce of the space object one does not simply grant itself an extension of technological presence in outer space by increasing the number of space objects, but also provides other space actors with clarity towards ones actions, possessions, and operations. Without the von Neumann doctrine, one might imagine the "theft" of produced structural parts for robots or space stations, produced from lunar resources by an external robot. The "theft" might be conducted in accordance with the OST, because one does not need to ask for permission to use space artifacts that are neither registered or outside of one's national jurisdiction. It's not so a wild west hypothesis but a lesson learn from the wreck scavengers from the wild deep seas prior to the adoption

of several crucial rules on historical wrecks and sunken warships[44]. Some humans have a nasty habit of "snatching and running" of a "no man's treasure", thus space law needs to adopt several additional rules in order to avoid disorderly behavior and bad customs in outer space. Von Neumann's doctrine provides the owner of the primary space object with both the extension of jurisdiction and control, as well as safety from unauthorized use of space objects and products. Also, it provides requirement of registry and liability for any damage caused by these space objects that were manufactured in outer space. Otherwise one may easily use "Rods from God", a kinetic projectile weapon as a form of piracy or "astropolitik[45]", where one may refrain from liability by simply stating that these weren't their projectiles, as even if they were traced back to the manufacturing facility, the accused might still argue that the mere fact of manufacturing does not make them liable for damage done by this object, as it cannot be directly, ex lege, be recognized as the property of the manufacturing entity and being under its state of registry's jurisdiction. Thus it is very reasonable to extend the jurisdiction and ownership from manufacturing objects onto their progeny.

However, one must take into account that space objects may vary in size as well as in composition. Self-replicating technologies might take the form of large complex robotic systems as well as microrobots and synthetic or hybrid organisms[46]. In that aspect for both safety reasons and reasons described in further chapters, the von Neumann doctrine of jurisdictional and ownership heredity should be established in order to aid and safeguard the beneficial outcome of outer space operation.

6. BIOLOGICAL SPACE OBJECTS AND INDUSTRAFORMING

One very controversial point to be made is that space law needs to reconsider the blend between hylotechnology[47] and synthetic biotechnology or materials and robotic systems purposefully imitating the behavior or natural abilities of biological organisms. Such abilities would include repairing, healing, replication, or reproduction as additional features that could increase the sustainability of space operations. There is currently a lot of debate on the use of engineered organisms in ISRU as mining and processing elements, as well as in some future allowing them to build a mound or colony-like structures. Other applications involve life support, agriculture, medicine, manufacturing, IT hardware and robotics, and even environmental engineering[48]. The main promise of biological space objects is their miniature size and scalability dependent on the availability of local nutrients.

The idea of seed factories or seeding life is probably as old as discussions about the possibility to live and thrive beyond the boundaries of Earth. There are however drawbacks to the idea of a single machine able to produce everything and anything that is stored in its data storage – even itself. The problem is that while a plant can basically grow from a seed and microbes can multiply geometrically within days, they are dependent on the environment itself. A seed under a transparent dome on the Moon won't grow into a plant unless it has suitable soil. Although the majority of "seed factory"[49] concepts were related to biology-based self-replicating space objects, there is a case to be made for living space objects. While it is assumed that most space objects are hylotechnological, aka non-living creations, this has been true throughout the entirety of space exploration. However, concepts of engineering living materials, mycelium, and biomining for space exploration tend to gain

more attention in academic circles. Biological organisms share a variety of features with artificial self-replicating space objects upon which they are based. The majority of space objects proposed by different authors which would possess the capacity to self-replicate, metabolizing space resources[50] and replicate using the principles outlined by John von Neumann and Edward Moore tend to only differ from biological organism in their design. While evolutionary mechanisms helped to shape natural organisms, human intervention helped to intelligently redesign organisms to better serve humans and their industry. On the other hand we have the concept of robots in living mediums, such us xenobots[51].

Space objects are mainly hylotechnological machines and payloads launched into space or constructed in outer space or celestial bodies, as well as launch vehicles and their parts and components. As article VIII states, parties retain jurisdiction and control over objects carried out on their registry, launched or assembled, or constructed in outer space. That concept is true to robots and base components, although the question of mining and jurisdiction remains. Space law still has no clear answer to what would be the legal status of machines or structural elements that would be created on-site or in space generally, using extraterrestrial resources or mixing them with elements and components made on Earth. One of the 1979 Moon agreement's provisions might serve as a basis for recognizing objects created on-site, and moreover, from local resources or by other space objects as falling under the same jurisdiction as the "mother object"[52]. This is also where Von Neumann doctrine of inherited jurisdiction comes in. The purpose of establishing this doctrine is the creation of a stable system under the current framework of international space law, that would provide legal recognition for space manufactured produce and systems created outside of the Earth. Although none of the ongoing projects even nearly resembles a Von Neumann universal constructor, the Bracewell/Arbib probe or the Dyson Mining probe, the experiments with microgravity 3D printing and ZBLAN optic fiber extruders are just the beachhead of new concepts of space law – Objects creating objects. This stems from the notion that objects possessing manufacturing capabilities in outer space would create other objects, whether simply programmed products or even their replicas. Therefore it is necessary to adopt a doctrine that would enable state parties to recognize and operate in a quasi living space environment teeming with industrial robotic activity.

However the question of applying the same rule or even treating organisms as space objects stems from a different part of the space manufacturing conundrum. It stems from the self-replicating technology doctrine in Patent law. According to the doctrine of self-replicating technologies, if an object with a specific purpose and additionally a built-in self-reproducing or self-replicating mechanism creates a copy of itself then this copy is treated as a completely new object. In the case of patent law, that means that despite exhausting the patent upon the first sale, the purchaser of the product possessing self-replicating capability is not allowed to benefit from this capability nor introduce the "natural copies" of the product to the market in any functional form[53]. This doctrine, although first used in cases between Monsanto and farmers[54] by synthetic biotechnology companies, is clearly applicable to machines that, among other features can self-repair or self-replicate, which have been a concept in space exploration for nearly a century[55].

However, the advancements of synthetic biology and xenobiology are likely to create a different form of space objects – living space objects[56], bio or xenobiotechnological instead of traditional hylotechnological. We can see synthetic biology and robotics blend in soft robotics, mining, or using biosensors for interior systems of space stations. It might be a stretch to call them space objects, but in the current state of international space law, there is no other way to regulate this technology and its application in outer space. For example, there isn't much functional difference in small, self-replicating microrobots doing their job as miners, constructors, or repairers, and programmed and tailored organisms with similar features and performing the same actions. Both raise concerns of possibly evolving, multiplying uncontrollably and causing harm and damage to the environment, celestial bodies, or space objects. Robots on the other hand are easily reprogrammable, thus they might not evolve but be purposefully redesigned and might also fall to the category of civilizational threats such as grey goo or a paperclip maximizer. Treating EVA-able synthetic organisms as living space objects will not only help on expanding the exploratory and industrial presence in outer space but also regulate the unregulated field of future activities. For In-Object operating synthetic organisms might not need special treatment under international space law, those operating outside, on the surface of planets or being "components" for one, like Dyson's "Astrochicken"[57] would require international recognition and registration. This stems not only from the requirement of international space law that states bear international liability and responsibility for the actions of their objects (living, robotic or operated remotely) but also from the notion of private space endeavors needing clear answers and legal safety from harmful actions of other space actors. An example would be collecting one's EVA capable microbes or other more complex organisms by another party. If the objects bear no registry and no state holds jurisdiction over them, what is to stop the third party from appropriating several of those organisms and using them for their own purpose, without asking for any permission or reproducing them and selling their copies to other space-faring actors.

However, we need to bear in mind the problem of contamination that might surely occur with organisms that are not specifically modified for non-contaminating functioning. Avoiding biological contamination of habitable zones of studied celestial bodies is being regulated by COSPAR, but there is also the problem of debris. If organisms are treated as space objects, those going "rogue", deceased or otherwise non-useful might be dealt with accordingly with the principles regulating space debris remediation and mitigation. On the other hand, self-replicating robots might also be seen as a form of contamination, as their introduction to the environment which they might thrive, using the surrounding resources means to multiply from may be viewed as harmful by space law and planetary protection scholars. While there are still concerns regarding contamination of celestial bodies, there is a case to be made, that objects which in their structure involve protein-based microrobots or synthetic microbes made of actual terrestrial organisms will require both a proper regulation and recognition. There isn't much difference between programmed living organisms and programmed replicating robots actively operating on the outer hulls or being a structural element, as in the case of mycelium or ELMs. Similarly, any operation that would prepare the ground for farming or industrial activity which would involve microbes or microrobots will spark controversy in the light of current regulations which prohibit any form of claims of sovereignity based

on the fact of homesteading. Inoculating a patch of Lunar or Martian dirt with tailored xenobiological organisms or robots for industrial purposes such as reducing the need for blasting, heavy machinery, and decreasing the amount of waste fluid or fluid usage will certainly have its legal repercussions. The fact of the matter is, there is no certainty whether a patch of ground being transformed by organisms or robots remains the same Province of Humanity, as it would be after a mining operation. The idea is that while removing soil or rocks leaves the remaining rocks free for others to mine or build upon or even create a landmark for tourists to visit, a part of a terrain which has been transformed and includes organisms or robots which fall under one's jurisdiction and their actions might create a national responsibility for the state that has authorized and supervised their use on a given celestial body. The problem of soil inoculation or other changes to local environment has not been addressed in any of the four main space treaties, and only appears in the Moon Agreement. It creates a tricky problem where space objects are intermixed with natural materials which will eventually have to be addressed in future space regulations, as the possibility of creating a bio-inspired space resource activity would provide more sustainability to such operations on an industrial scale[58].

And although the idea of space objects intermixing with the natural material of a celestial body might seem an overstretch, the idea of recognizing artificial or synthetic living organisms operating outside or creating the exterior of a space object as space objects or their components makes lots of sense in cases where such technologies would be employed and furthermore it would fulfill the obligation to register one's space objects for the sake of space safety. Proliferation of space objects manufactured or bred in space will require the same approach to space objects.

Treating living organisms as living space objects might be the first step in bridging the gaps that have been developed by completely different developments of space law and patent law throughout history. In this case the concept of inheriting of jurisdiction could be viewed as at odds with the current state of international space law, as it may be argued that the use of this doctrine allows one state to presume ownership over the whole "artificial biota" that starts inhabiting a celestial body or it's orbital space. Space law has not foreseen this problem with launching or assembling machines in outer space and on celestial bodies. Whether autonomous or with cooperation with ground controllers or astronauts, these machines might start to work as a form of a machine ecology, similar to natural biological symbiosis. As one needs just to look at the concept of the Self-Replicating Growing Lunar Factory[59], the conceptual structure made out of dozens of machines actually resembles a clanking simulacrum of natural terrestrial ecologies. If all elements of the orbital space industrial environment, including servicing, transferring, manufacturing or disassembling would've been fully automated, one could not be left unamused by the biomimicry, the lifelikeness that these artificial sustainable systems tend to show. In the present day regulations of space law, covering a celestial body with either machines or organisms that can self-replicate or with inanimate leftovers from space probes does not constitute national appropriation nor can be any basis claims of sovereignty over the body or regions of thereof. The actions of mining, manufacturing or constructing object does not give any nation the right over the unaltered soil nor rock that remains in its natural state. This might in effect pose a question of altering a celestial bodies ecosystem using hylo- or biotechnology, however, it has to be clear that the von Neumann doctrine only applies to

purposefully created objects. If a hardened road is constructed between bases, to ensure safer and more energy-efficient travel for the crew or machines, then the doctrine would apply, as opposed to a road that has been made merely with tracks of vehicles cruising back and forth.

An altogether different reason for this doctrine is the possibility of replicating errors[60], evolutionary mechanisms and other factors that might occur with self-replicating or manufacturing the mother object's progeny. If there is no responsibility, no jurisdiction nor control, and authorization, that creates a dangerous conundrum for the international space law. The other problem that is also to be realized is that patent law follows the national jurisdiction of objects outside of national borders[61]. Thus in order for outer space to remain "sans frontiers", the patent law must follow the islands in the sky model, especially where production and self-replication is concerned.

7. THE HERMIT CRAB DOCTRINE

The other side of the Von Neumann doctrine is the Hermit Crab Doctrine. Although it might also be referred to as the Frankenstein doctrine, the hermit crab better suits the Ship of Theseus principle in civil law. The ability to create space object and equipment out of available materials does not only limit itself to rock breaking and regolith filtrating robots but also the reusability of any elements of space objects, which have deliberately or accidentally lost their functionality. Even cannibalizing debris for useful materials or spare parts tends to be brought up in academic discussions on in-space recycling or upcycling. We could imagine a concept that would address the issue of reusing parts of broken space objects for them to be incorporated into a still-functioning object, or foreign freshly manufactured objects being incorporated to repair and extend the use of a space object. We propose the concept of a Hermit Crab doctrine. As we know, hermit crabs tend to reuse shells and other elements that have been discarded or abandoned by other marine organisms, due to the lack of one's own calcified protective exoskeletal abdominal shell. In this case, an object, similarly to the crab or Plutarch's[62] and Hobbes's Ship of Theseus[63], will incorporate new parts or parts and elements taken from other objects for their use, such as expanding one's capacity or repairs. This doctrine would allow the transfer of space object components and parts in compliance with the space object openness principle presented in article XII of the OST. For example, elements from defunct foreign space objects can be cannibalized and upcycled into the currently operational space object to prolong its operations and preserve its integrity. This would in many way create a legal route for any space debris recycling/upcycling operations, especially on a broader scale and greater frequency than contemporary attempts of prolonging the operation of a comsat or testing space debris removal via external deorbiters/space tugs. This would require dramatic changes in the way nations carry out their registration duties, while also address the idea of "jurisdiction and control". The doctrine states, that unless there is a different agreement among parties, any legally obtained space object, whether be a part, component, or spare mechanism made or customized for a larger space object falling under the control and jurisdiction of one party, that has been manufactured by another party, is being treated as an integral element of the space ob-

ject upon application, assembly or installment if prior handing over of the objects control or jurisdiction hand not taken place.

This conceptual doctrine of international space law is made to address the limitation of the von Neumann doctrine. This might be illustrated on two examples:

- Example #1, State party one is in possession of a lunar manufacturing facility, that creates structural elements for surface, subsurface, and orbital stations out of lunar resources. State party two plans constructing an inflatable habitat in Earth orbit, but the design requires structural elements that cannot be transported from Earth without a cost overhaul. State party one is contacted by state party two to , which ordered the creation and transport of specified structural elements to a rendezvous point, where they will be picked up by manual-robotic or automated assembly units and made into the frame of the space station. Upon arrival, to the rendezvous point the structural elements are either handed over and re-registered by the means of inter partes contract, or by the application of the hermit crab doctrine. In effect, the structural elements have the same registration as the elements launched and registered with the State party two.
- Example #2, state party one operates a manned space station that functions as a scientific outpost in the 5th Solar-Venerian La Grange point. This station has suffered numerous damage to its exterior structure and shielding due to a micrometeoroid shower that was a product of a comet passing by the sun some time ago. State party 1 has no way to repair its station on-site due to the lack of materials and manufacturing capacity (the crew is equipped only with basic repair tools and a small topdown material 3D printer, which manufacturing ability is restricted only to the most basic spare parts). State party one contacts state party two, which operates several robotic manufacturing units over every major inner system body and is able to reach the station via lightsail or nuclear/laser-thermal propulsion. Depending on the amount of damage and the availability of local resources (collectible debris or scrap metal) State party two launches either full sets of easy to use plates of shielding that are in line with the specification sent by stare party one, or other crucial hull elements, or a manufacturing robot capable of producing these on-site. According to the von Neumann doctrine, those elements produced on-site by the repairbot or being sent in packets from state party two's manufacturing units would therefore be treated as belonging to state party two. In this case, one might see the problematic position that state party one would be in if the hull needed more than 50% of its structure repaired or replaced with articles manufactured by state party two.

The Example #2 perfectly shows the problem with extending jurisdiction to manufactured products if they are to serve other parties. In this case, unless the parties have contracted otherwise, the foreign elements that were added to the original structure to prolong its service or were produced to retrofit, modify or even establish a new object fall under the jurisdiction of that object. This only may occur when the transfer and implementation is legal.

Example #3 goes as follows:

- Example #3, State party one owns and controls a multipurpose planetary surface rover, which can manipulate, cut and weld, and assemble a certain spectrum of objects and materials. Due to the harsh environment of the rover's place of operations, it has broken one of its six wheels. Although wheels work independently, the broken wheel creates a drag that causes increased expenditures of onboard energy, while on the other hand, its removal would cause the rover to lose some stability, which might have dire consequences when roving through the regolith and crater covered surface of a natural satellite. However, the rover or it's remote controllers discover a broken down rover which was sent here by State party two some time ago. Representatives of State Party one contact state party two and ask for the details of their rover breaking down. Furthermore, invoking the Article XII of the OST, they ask for permission to use one of their rover's functional wheels as a replacement for their broken wheel, as they seem to be of similar design. Upon agreement, the controllers or the rover itself commences the repair and replacement of the part. The hermit crab doctrine states that now the new wheel is an integral part of the operational rover.

Example #3 is the one that might be useful when considering remanufacturing and cannibalizing parts from dead satellites or other space debris. The reusability of broken systems and vehicles should be viewed as an opportunity for space policymakers, as one not only mitigates major space debris creation but also remedies the existing problem in some aspects. However, this process needs to be Legal in accordance with international space law as well as national procedures for re-registration and export of space technologies. In the case of unauthorized seizure of space debris special provisions must apply in accordance with national laws, or severe analogies need to me performed under the international space law to consider theft of an object or its component as piracy or damage caused to a space object. Space law should not allow one party to "PacMan"[64] up space objects belonging to other states in a fashion reminiscent of the "You only live Twice"[65]. Allowing unauthorized incorporation of space debris, dysfunctional systems might lead to other dangerous development akin to piracy or leaching. Thus unless otherwise stated, like in the ISS IGA for example, objects that became incorporated into other space objects become their components and fall under the same jurisdiction as the main object. The Hermit Crab doctrine would enable establishing a rule similar to Accessio principal in European civil law, or the repair-reconstruction doctrine in patent law. The rule states, that an object that is incorporated as a part of a larger object becomes is to be treated as a part of this object, in the similar matter that male anglerfish become integral parts of the female. In essence, any part of a space object, upcycled from a defunct space object or its component would automatically become an integral part of the object that it is added to, as if they would be of the same registry, under the same jurisdiction and control. It would not exclude parties agreeing to a patchwork jurisdiction analogous to that of the ISS. However, this would also erase the possibility of unwarranted extension of one's jurisdiction over foreign space objects, liability issues in the case of additional components attached or salvaged as well as it would clarify most issues with IP infringement prosecution.

There is also the question of objects which dock with each other and perform payload transfer, orbit transfer or other services in outer space. This however shall be brought up in the paragraph discussing the issues revolving around patent law. However, we need to keep in our minds the specificity of what space object based jurisdiction implies to any discussions of transfer and extraterritoriality.

Tying together the Von Neumann Doctrine and the Hermit Crab Doctrine may ensure the legality and responsibility of space manufacturing operation, whether it'll use simple manufacturing methods, complex systems, microrobots, or synthetic organisms. Although there is one administrative system that needs to be reformed in order for those doctrines to succeed. That is the registry system. The registry system might be susceptible to "overload" due to the number of new objects appearing and disappearing. Without proper registration however, lost objects may not be "found" or identified and retrieved to the rightful owner. Furthermore, registration allows states to retain national jurisdiction over their properly registered objects which allows national laws to follow. And patent protection is mostly covered by national borders and does not extend over their lines. If a national border in outer space is defined by the space object like a mobile or immobile "island in space", the creation of other objects, manufactured by their respective mother objects, such object needs to be provided with proper registration and fall under the same jurisdiction as the mother object. If left unprotected by the registry, any space object might become incorporated or used by a foreign entity, out of malice or lack of contact information through ITU or UNSG.

8. CONCLUSIONS

Space Shoggoths and other space objects possessing the manufacturing and replicating capabilities will require new sets of rules, that are beyond the scope of the present discourse of international law. At the current state mostly nationals laws and intergovernmental law proposals tend to address the problems that will arise from objects actually utilizing space resources, and those that would reuse existing space debris and wreckage. Additionally, space law should revise its approach towards life in outer space, as the approaches presented in this paper show how close robots can become to living organisms, and how biological solutions in architecture, mining, manufacturing, and electronics would create new legal conundrums. The proposed ideas of the von Neumann doctrine and the Hermit Crab doctrine tend to address the basic international legal considerations regarding ownership and jurisdiction.

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