Vilnius University Faculty of Law

Department of Private Law

Marcus Fabian Brinck,

II study year, International and European Law Program Student

Master’s Thesis

Managing Space Debris in the Age of Small Satellites: Proposals for Regulatory Action

Kosminių šiukšlių valdymas mažų palydovų amžiuje: pasiūlymai dėl reguliavimo veiksmų

Supervisor: Lecturer Dr. Paulius Jurčys

Reviewer: Lecturer Dr. Neringa Gaubienė

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ABSTRACT AND KEY WORDS

This work analyzes the international legal framework addressing the growing population of space debris and the therefrom resulting issues for space activities. For this purpose, the international space treaties as well as various guidelines by the United Nations and other international institutions and organizations are assessed to identify aspects of the international legal framework which could be improved. In particular the increased debris generation from the commercialization of space and the emerging trend of using large numbers of small satellites needs to be considered in order to create an appropriate legal framework capable of managing space debris.

Keywords: space law, small satellites, space junk, space debris, law and technology.

Šiame darbe analizuojama tarptautinė teisinio reguliavimo sistema, skirta didėjančiam kosmoso nuolaužų kiekiui ir iš to kylančioms kosminės veiklos problemoms spręsti. Šiuo tikslu vertinamos tarptautinės sutartys dėl kosmoso, taip pat įvairios Jungtinių Tautų ir kitų tarptautinių institucijų bei organizacijų gairės, siekiant nustatyti tarptautinės teisinės sistemos aspektus, kuriuos būtų galima patobulinti. Visų pirma tam, kad būtų sukurta tinkama teisinio reguliavimo sistema, galinti užtikrinti tinkamą kosminių nuolaužų valdymą, reikia atsižvelgti į tai, kad dėl kosmoso komercializavimo bei dėl augančios tendencijos naudoti daug mažų palydovų, kosminėje erdvėje atsiranda vis daugiau šiukšlių.

Pagrindiniai žodžiai: kosmoso teisė, mažieji palydovai, kosmoso šiukšlės, kosmoso nuolaužos, teisė ir technologijos.

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LIST OF ABBREVIATIONS AND DEFINITIONS

ADR	active debris removal
Art.	Article
ESA	European Space Agency
e.g.	for example (*exempli gratia*)
FCC	US Federal Communications Commission
GEO	Geostationary orbit
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordination Committee
ITU	International Telecommunication Union
LEO	Low Earth orbit
Liability Convention	1972 Convention on International Liability for Damage Caused by Space Objects
Moon Agreement	1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies
Outer Space Treaty / OST	1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies
p. / pp.	page / pages
para.	paragraph
Registration Convention	1975 Convention on Registration of Objects Launched into Outer Space
Rescue Agreement	1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space

INTRODUCTION

Space has always been the final frontier for human exploration, where only in the last century first steps of humanity have been made. While these original endeavors were only possible due to the vast funding of whole nations, today we are entering an age where space is more accessible than ever, termed “NewSpace”, which is characterized by private actors and commercial enterprises who are now the main drivers of the development of the space sector. By today, many large corporations like SpaceX with their Starlink or Amazon with their Project Kuiper are planning to utilize thousands of small satellites to create large constellations in orbit. The emergence of small satellite technologies, which has made satellites much cheaper and more flexible, has however not only benefitted the big players, it also allowed private actors to engage in space activities, for example as part of university projects. With this development, however, also come risks for Earth: Space debris has become an increasingly threatening problem as a consequence of the large numbers of new objects in space around our planet. The debris pieces, mainly consisting of non-functional leftovers of rockets or satellites, pose a growing risk to our satellite infrastructure, which is crucial for the global telecommunication and internet sectors, and accordingly for the functioning of our modern world. It is estimated that the space debris population could spiral out of control when it reaches a certain density, as the collisions between debris pieces break them up even further, creating even more debris in the process which in turn leads to even more collisions. How close we potentially are to such a scenario and how little we are in control of the situation was again shown recently, when the target of one of the first planned debris removal missions, a leftover part of a European Vega rocket launched in 2013, was recently hit itself by a small, undetectable piece of debris, causing more fragments to break off and creating even more debris while raising concerns of the success chances of the mission (Objects detected in the vicinity of ClearSpace-1…, 2023).

Relevance. The utilization of space technology now forms a crucial part of everyday society in all parts of the globe – irrespective of the (geo)political, economic, societal, and cultural characteristics of any one country (Freeland, 2019, p. 1318). This is even more true today, as the capabilities but also the dependencies on satellite technologies steadily increase. However, with the exceedingly growing number of satellites launched, the risks stemming from space debris are increasing likewise, as a dense debris belt could have the potential to render Earth’s orbits unusable for satellites or any other space activities. Consequently, in order to preserve not only the ability to further explore space but also the function of our modern society, the timely creation of a legal framework able to manage the risks of space debris is indispensable.

Aim. This is why this Master's Thesis aims to assess the current status of the legal framework addressing space debris with particular focus on the issues that small satellites bring in this regard and to identify what aspects and measures are important to reach a desirable legal framework able to appropriately tackle the space debris issue. In particular the questions whether an international solution is truly necessary or whether the national law of individual jurisdictions is sufficiently equipped to handle the issue, what kinds of international legal instruments might be appropriate and whether or not the evolving small satellite technologies need to be addressed specifically in such a legal framework should be answered. Subsequently, concrete proposals can be made on how to improve the international legal framework on space debris.

Tasks. The tasks of this Master's Thesis are therefore,

1. to assess the current status of the international legal framework concerning space debris;
2. to evaluate whether this existing framework is sufficient with particular consideration of the characteristics of small satellites;
3. to determine what approaches and measures could or should be taken to create a desirable legal framework to manage the space debris issue.

Objects. The objects of this Master's Thesis will be the various instruments of international space law, as the space debris issue poses a global threat which should accordingly be addressed on an international level.

Methods. The methods of this Master's Thesis include mainly the review and comparison of the legal instruments concerning space debris, in particular the international agreements on space law related matters and various international guidelines on this matter. Existing arguments and opinions of legal scholars and institutions in regard to this matter will be evaluated as well. Beyond this, also the practical statistics and approaches on how small satellites are operated will be assessed.

Originality. This Master's Thesis approaches the legal issues of space debris with focus on specific issues created by small satellites. In this context, an independent review and evaluation of some of the most recent legal and policy documents on space debris will be conducted. Reviewed will be, among other sources, the ESA Zero Debris Charter and the Space Industry Debris Mitigation Recommendations of the World Economic Forum, which have only been published in the recent months. Moreover, the concrete proposals made in this paper will be, *inter alia*, based on the results of this individual evaluation.

Most important sources. The most important sources include the international space treaties, particularly the Outer Space Treaty, the Liability Convention and the Registration Convention, as these constitute the primary source for the existing space law concerning small satellites. Furthermore, international guidelines and recommendations of the United Nations and of other organizations addressing space debris will be evaluated. Additionally, books and articles by scholars will be included in the preparation of this Master's Thesis to comprehensively cover the legal landscape of the chosen topic. This includes in particular the work of Hobe for a general overview of space law related matters, as well as the work of Marboe, which covers various aspects of the legal challenges of small satellites.

1. FACTUAL BACKGROUND OF THE SPACE DEBRIS ISSUE

Before being able to identify and assess the legal framework attempting to regulate and control space debris, the factual background of this issue needs to be understood, in particular, the nature and sources of space debris and the practical problems caused by it. The next paragraphs will thus give an overview of the issues caused by space debris (**1.1.**) as well as of the nature of small satellites (**1.2.**) and why they pose a specific challenge with regard to space debris (**1.3.**).

1.1. The Issue of Space Debris

Today there exists a manifold of objects in space, particularly in orbit around Earth. This includes not only man-made objects, like leftover rocket parts from past launches or satellites but may also include natural objects, such as meteorites and dust. Consequently, it is important to define what shall be understood as space debris in the legal sense, before pondering potential solutions to the debris problem. As a starting point it should be noted there exists no uniform binding definition of what qualifies as "space debris". There are however various definitions by different institutions, for example by the Space Debris Working Group of the European Space Agency ("**ESA**"), the International Academy of Astronautics ("**IAA**"), the International Law Association, and by the Inter-Agency Space Debris Coordination Committee ("**IADC**"). Even though these definitions do vary in detail and exact phrasing, all of these have in common that they characterize space debris as man-made objects in outer space which do not serve any purpose (Hobe, 2023, p. 99). In practice, such a definition will mainly capture in its scope non-functional satellites or such satellites, that have concluded their mission, leftover parts of launch vehicles, like rocket parts which were separated and left behind, as well as pieces of any such man-made space objects which are the result of collisions. From this follows that natural objects in space or specifically in orbit around Earth are not considered space debris in the legal sense.

According to estimations by ESA, there are currently 130 million space debris objects between 1 mm to 1 cm in size, 1,000,000 space debris objects between 1 cm to 10 cm in size, and 36,500 space debris objects greater than 10 cm in orbit (Space debris by the numbers, 2023). It is further estimated that there are currently 8,600 functioning satellites in space and 1,990 satellites still in space which do not function anymore. The estimated number of break-ups, explosions, collisions or anomalous events resulting in fragmentation amounts to more than 640.

New space debris is not only created when new space objects are brought into orbit, but also regularly when already existing space objects collide. Such collisions can take place between two functioning space objects, in particular satellites, one functioning object and a debris object, or between two debris objects, which fragment even further. One of the first large-scale incidents in this matter was the collision between the then-active US satellite Iridium 33 and the non-functional Russian Kosmos 2251 in February 2009, which created an estimated number of 1,500 – 2,000 pieces of debris larger than 10 cm and thousands of smaller pieces which might remain in orbit for years (Hobe, 2023, p. 99). Debris may be also created through anti-satellite testing activities, where the military possibilities of destroying satellites are tested. A prominent example of such an activity was the destruction of the Chinese satellite Fengyun-1C in 2007 during an anti-satellite missile test conducted by China. The destruction of the satellite led to the creation of more than 1,000 space debris pieces bigger than 10 cm (Hobe, 2023, p. 100). These two events constitute a turning point in which the main source for the creation of new space debris was no longer caused by explosive breakups of rocket bodies, but by collisions and destructions of satellites (Braun, 2020, p. 261-262).

The risk space debris poses for space activities can not be understated, as even small pieces could potentially cause serious damage to other space objects. While the exact risk depends on various factors, such as the mass, orbital velocity, size of the impacting object, and the material properties of the shield of the spacecraft, with an average impact velocity of 14 km/s in low Earth orbit already a debris piece larger than one centimeter could potentially penetrate the pressurized crew module of a manned space station, leading up to the destruction of the space station (Hobe, 2023, p. 99).

Finally, an important concept when it comes to space debris is the so-called "Kessler Syndrome" (Braun, 2020, p. 264), named after the scientist Donald Kessler, who first described this effect in 1978 (Kessler, Cour-Palais, 1978, p. 2645). According to this concept, particles colliding with other space debris objects will create more debris, leading to even more collisions and thus causing an exponential growth in debris and to the creation of a debris belt in orbit. Such a dense layer of debris could pose a significant threat to space operations. Already a study from 1989 concluded that portions of the low Earth orbit might become so congested with space debris that they would be unusable within the next few decades (Baker, 1989, p.13).

1.2. The Nature of Small Satellites

While traditional satellites are often large and costly, like communications satellites in geostationary orbits ("**GEO**") which can be as large as multi-story buildings, small satellites are supposed to be simple, specialized and mass-produced (Lyall, Larsen, 2018, p. 239-240). This already which makes them significantly cheaper and thus more accessible to various actors. Due to their usual deployment in low Earth orbit ("**LEO**"), an orbit with an altitude of up to 2,000 km above the ground, they also allow for a reduced transmission path loss and easier as well as cheaper launches (Pelton, Madry, 2020, p. 24). However, similar to the term "space debris", also no officially recognized unified definition of what exactly counts as small satellite exists (Von der Dunk, 2016, p. 160). So do the international space treaties, as most important source of the space law framework, not contain any definition for what qualifies as a small satellite, moreover no reference is made in general to the size of the "space objects" which are mentioned in the international legislation. Instead, varying definitions of scholars and institutions were created, with one of the most recognized ones being the definition of the International Academy of Astronautics, which considers all satellites with a mass of less than 1000 kg small satellites (Marboe, 2016, p. 3). In more detail, the following definitions for even smaller satellite categories are made: mini satellite (less than 500 kg), micro satellite (less than 100 kg), nano satellite (less than 10 kg), pico satellite (less than 1kg) and femto satellite (less than 100g). While in the various definitions the starting point of what constitutes a small satellite in general may differ, some already qualifying a satellite not bigger than 200kg a small satellite, the thresholds for the subclasses are generally accepted in a similar manner (Hobe, 2023, p. 23). Noteworthy when discussing types of small satellites are also the so called "CubeSats", which are square, cube shaped satellites that is made up of multiples of 10*10*10 cm units. These CubeSats were developed originally in 1999 in the USA by the California Polytechnic State University and the Stanford University for educational purposes to enable graduate students to build and develop their own satellites (Sweeting, 2018, p. 351-352).

The possible use cases for small satellites range from scientific research and education, testing of new technologies and earth observation and communication purposes to even military applications (Marboe, 2016, p. 4-5). Their use has steeply increased in the recent years due to the lower costs of development and deployment as well as due to the wide application for experimental and commercially viable activities (Hobe, 2023, p. 23). Around 94% of all the spacecraft launched in 2021 were small satellites (Smallsats by the numbers 2022, p. 2). According to some estimations the small satellite market will increase significantly within the next ten years (Global Small Satellite Market, 2023). In general, the current era, which has been called "NewSpace", is characterized by a shift from the traditional model of government-led space activities to a business and industry-led space environment, sparking the emergence of large numbers of companies seeking to deliver new applications or pursue new approaches of operating in space (Sweeting, 2018, p. 353).

A specific way of using small satellites which becomes more and more prominent is the use of large constellations, where a group of similar satellites consisting of hundreds or even thousands of small satellites would be used to achieve a certain objective in areas like navigation, telecommunication or Earth observation (Braun, 2020, p. 268). In these constellations, the small satellites are designed to function together and greatly increase the capabilities that each individual satellite might provide, in the theme of the result being greater than the sum of their individual parts.

1.3. Small Satellites as Aggravators of the Space Debris Issue

Small satellites have inherent peculiarities which make them prone to aggravate the space debris issue. In concrete terms, these issues stem from several aspects of the design and use of small satellites.

Firstly, due to their small size and usually more simple design they often lack the same technical capabilities as their bigger counterparts. Beyond the usual basic subsystems, such as power supply, telemetry, an on-board computer, thermal control and a payload, not many capacities are left for further systems; for example, small satellites often only use a battery as energy source with a usually rather short lifetime and they might lack control capabilities (Hobe, 2023, p. 24). While modern satellites used in constellations usually are able to maneuver, other types of small satellites like CubeSats still largely lack such capabilities (Pelton, Finkleman, 2020, p. 131). Lacking maneuverability is critical in two: Not only does this exclude the possibility for small satellites to actively avoid imminent collisions with other space objects, but it also creates difficulties for the post-mission removal of the satellite, as the satellite might not be able to lower its altitude to de-orbit or increase its altitude to a dedicated graveyard orbit. Both of these aspects lead to a higher risk of creating more space debris, either if the small satellite or its constellation collides with other objects in orbit and creates new debris due to the destruction, or if they stay in orbit after the end of their mission and becoming dysfunctional and thus become debris at that point themselves.

Secondly, small satellites have regularly a shorter mission time than the traditional larger satellites. While the larger satellites usually are designed to stay in orbit for up to decades, small satellites are often only meant to stay in orbit for shorter periods of time until they should be replaced; they often have only an envisaged lifespan of three to five years (Suwijak, Li, 2021, p. 139). Next to the technical limitations of small satellites and their power sources, small satellites are also often on purpose replaced relatively fast to update and re-design them to be compatible with the newest technical developments, which may be particularly relevant for satellites providing internet services. A shorter mission time and higher replacement rate means the deployed satellites need to perform post-mission disposal measures, like de-orbiting the satellite, more frequently. Considering the inherent potential of failures of such maneuvers, the total number of satellites becoming debris due to failed disposal measures increases thus as well.

Thirdly, the emerging popularity of using of small satellites not as individual objects but in large constellations with up to several thousand satellites at once aggravates the above-mentioned issues even more. While an individual satellite without maneuvering capabilities or the re-deployment of one satellite every few years might not lead to a fast increase in the amount of space debris, having thousands of such events happen regularly might do so. Additionally, the existence of large numbers of satellites in formation also naturally increases the chances of collisions with other space objects, further increasing the risk of debris creation. Also failures in the design stage of a satellite, in particular concerning its maneuver or de-orbit capabilities, could cause significantly more issues when it affects a large number of identical satellites in a constellation.

In summary, the limited technical capabilities as well as the specific use of small satellites in large constellations with relatively short lifespans leads to a new level of risk of creating more debris, which might push the triggering of the "Kessler Syndrome" even earlier than originally estimated.

2. THE LEGAL FRAMEWORK ADDRESSING SPACE DEBRIS

Similar to other fields of international law, space law is not any single set of rules book of law, but rather a thematical concept describing various acts of regulation that concern matters connected in one way or another to space (Lyall, Larsen, 2018, p. 2). Accordingly, also the regulatory framework addressing space debris and small satellites consists of several different international instruments in binding and non-binding nature, as well as of the respective national rules of different jurisdictions. Firstly, the binding international legal instruments will be reviewed. These include in particular the five space treaties which were concluded between 1967 and 1979 and regulate various space related areas. Beyond these binding international rules, there exist also non-binding instruments which are more specifically tailored to address space debris and thus form an important part of the legal framework relevant for space debris. Some of the most prominent rule sets relating to space debris and sustainability include the Space Debris Mitigation Guidelines of the Inter-Agency Space Debris Coordination Committee, the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space ("**UNCOPUOS**"), and the UN Guidelines for the Long-term Sustainability of Outer Space Activities. Next to these regulatory guidelines exist also recommendations and documents drafted in cooperation with industry actors. In the context of the NewSpace development, which is characterized by the rising importance of private space actors, such instruments could include valuable insights in the position of the industry and could serve as examples for improvements of the regulatory framework. Two very recent documents in this regard which will be assessed are the Space Industry Debris Mitigation Recommendations by the World Economic Forum, and the ESA Zero Debris Charter.

In the following paragraphs firstly the binding international space law will be evaluated (**2.1.**). Secondly, the selected non-binding instruments which were created or endorsed by regulatory bodies will be assessed (**2.2.**). Lastly, the recommendations concerning space debris management created in cooperation with private actors of the space industry will be reviewed as well (**2.3.**).

2.1. The Binding International Space Law Framework

The basis of the field of space law regulations, which also constitutes the foundation of the rules relevant for small satellites, is primarily to be seen in the five United Nations treaties: the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 1967 ("**Outer Space Treaty**" or "**OST"**), the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space of 1968 ("**Rescue Agreement**"), the Convention on International Liability for Damage Caused by Space Objects of 1972 ("**Liability Convention**"), the Convention on Registration of Objects Launched into Outer Space of 1975 ("**Registration Convention**"), and the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies of 1979 ("**Moon Agreement**"). It needs to be pointed out, however, that the acceptance and thereby the relevance of these international agreements vary. While the Outer Space Treaty and the Registration Convention are signed and ratified by a large number of nations, the Moon Agreement has been as of now only signed and ratified by 18 states. Most prominently the USA as one of the major players in the space sector has not signed it, which leaves the Moon Agreement in particular as a less significant legal instrument. Additionally to these international agreements, several UN General Assembly resolutions are supplementing this framework.

So far no binding international norms specifically on space debris mitigation exist (Steinkogler, 2016, p. 214). The existing space law treaties do not cover this issue expressly and only some provisions could be interpreted in ways to cover space debris, however not in any comprehensive or satisfying manner. Art. I of the Outer Space Treaty states that the use of outer space shall be for the benefit and in the interest of all countries and shall be the province of all mankind. Art. IX OST establishes the principle that harmful contamination of outer space shall be avoided. However, no more details or the suggestion of concrete measures are included. While the interpretation of the notion "province of all mankind" could include a safe and clean environment, similar as the avoidance of "harmful contamination of outer space" could include contamination through space debris, such interpretation do not lead to rules or measures concrete enough for an effective legal framework (Hobe, 2023, p. 101-102). The Moon Agreement in its Art. 4 paragraph 1 introduces the concept of "intergenerational equity" for outer space activities, which however likewise lacks concreteness when it comes to an effective space debris rule set (Hobe, 2023, p. 102).

In summary, none of the above-mentioned international treaties address space debris expressly or provide any concrete and meaningful solutions. Accordingly, the existing binding legal instruments do not form an appropriate or sufficient legal framework when it comes to the space debris issue.

2.2. International Guidelines

A more express regulation on space debris can be found in various international guidelines. In particular, the guidelines endorsed or drafted by the United Nations will be assessed for the purpose of this paper, as these are the most prominent international rule sets with the best chance of being applied globally. These guidelines include the Space Debris Mitigation Guidelines by the Inter-Agency Space Debris Coordination Committee (**2.2.1.1.**), the Space Debris Mitigation Guidelines of the UN Committee on the Peaceful Uses of Outer Space

(**2.2.1.2.**), and the UN Guidelines for the Long-term Sustainability of Outer Space Activities (**2.2.1.3.**).

2.2.1. The Space Debris Mitigation Guidelines of the IADC

The Inter-Agency Space Debris Coordination Committee, which consists of representatives of several space agencies, including China, France, Germany, India, Japan, the Russian Federation and the USA, adopted their Space Debris Mitigation Guidelines originally in 2002, based on space debris mitigation standards and study reports of various national and international organizations, with updates following in the years 2007, 2020 and 2021. According to the foreword of the IADC Guidelines, the primary purpose of the IADC is to facilitate the cooperation between the space agencies in the mitigation of space debris. Even though the IADC guidelines are not created by a regulatory authority, they were endorsed by the UN General Assembly (UN GA Res. 62/217, 2007) as well as they are referenced in the guidelines published by the UN itself, and are thus *de facto* part of the UN framework addressing space debris. The aim of these guidelines is to recommend cost-effective debris mitigation measures for the planning and design as well as the operation phases of spacecraft in order to minimize or fully eliminate the creation of space debris during or after their respective missions. The four main focus points of the guidelines are:

1. the limitation of debris released during normal operations,
2. the minimization of the potential for on-orbit break-ups,
3. post-mission disposal, and
4. the prevention of on-orbit collisions.

The guidelines do in general not differentiate between different kinds or sizes of spacecraft or provide any concrete measures specifically for small satellites. The only mention of small satellite-related measures is made concerning post-mission disposal: The guidelines recommend in general a 25 year post-mission lifetime limit, within which spacecraft need to be removed out of orbit, while the probability of success of the disposal should be at least 90%. For specific operations such as large constellations the guidelines point out that a shorter residual lifetime or a higher probability of success may be necessary. There are, however, no further details or recommendations on how short the lifetime or how high the probability of success should be, this is instead left to the respective actors in practice. Also it should be noted, that these guidelines do not “outlaw” any certain type of space activity, but instead aim to provide guidance on how to conduct space activities in a way to prevent or at least minimize the harmful by-products of space activities in the form of the creation of space debris (Hobe, 2023, p. 103). They are therefore not an actual legal ruleset with consequences for violations, but rather a set of positive suggestions. The guidelines basically rely on the cost-effectiveness of the recommended measures and aim to convince space actors of their usefulness in order to promote their application.

2.2.2. The Space Debris Mitigation Guidelines of the UNCOPUOS

The UNCOPUOS Space Debris Mitigation Guidelines constitute one of the most important international legal documents concerning space debris. The most recent version was established in 2010 at the UN as the highest level of state cooperation and thus has the potential to make a significant impact on the global management of space debris, even though they are expressly not legally binding under international law.

Content-wise, the guidelines are largely based on the above-mentioned IADC guidelines. They divide debris mitigation measures into two categories: Measures that limit the generation of space debris in the near term and measures that limit space debris in the longer term. Near team measures mean in this context the avoidance of debris creation during spacecraft missions, while long term measures aim primarily at the post-mission removal of spacecraft from orbit. They take on the same definition of space debris as the IADC guidelines but do not define any other terms. The application of the guidelines is intended for the mission planning and operation of spacecraft. There are seven main guidelines that are recommended:

1. Limit debris released during normal operations
2. Minimize the potential for break-ups during operation phases
3. Limit the probability of accidental collision in orbit
4. Avoid intentional destruction and other harmful activities
5. Minimize the potential for post-mission break-ups resulting from stored energy
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit region after the end of their mission
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit region after the end of their mission

Compared to the IADC Guidelines, the UNCOPUOS Guidelines serve as more general and less technical guidance (Steinkogler, 2016, p. 220). For example, while both guidelines include the recommendation to remove spacecraft after the end of their mission time from LEO, there are no time limits or further instructions given in the UNCOPUOS Guidelines. The differences in these two sets of guidelines might come from the fact, that the IADC guidelines have been developed by experts from a small number of space agencies, while the UNCOPUOS guidelines had to be agreed upon at the political level by all member states of the UN Committee, where decisions are taken by consensus (Steinkogler, 2016, p. 221). Unfortunately, the broader and less specified a legal document is, the less impactful will it be. Without any specific instructions on *how* to achieve the aims of the guidelines, i.e. what measures should be taken to actually mitigate space debris, these guidelines rather function as a general set of goals instead of an effective legal framework. Furthermore, due to the broad nature of these guidelines, there are also no distinctions between different types of spacecraft or their applications, like small satellites and constellations, which might have needed more tailored recommendations. Consequently, the UNCOPUOS Guidelines in their current form are a rather toothless base document but they do not contain enough detailed guidance to expectedly handle the space debris issue in the current age of steeply increasing numbers of small satellites launched into Earth's orbits.

2.2.3. The UN Guidelines for the Long-term Sustainability of Outer Space Activities

The UN Guidelines for the Long-term Sustainability of Outer Space Activities were adopted by UNCOPUOS in June 2019 and form the most recent regulatory instrument on the UN level addressing the issue of space debris in the context of the long-term sustainability of the space environment. However, again expressly non-binding and only promoting a voluntary application.

The guidelines include a preamble and 21 different guidelines which address states and international organizations to voluntarily promote the implementation and practical application of the recommendations made therein. The content of the guidelines is divided into the categories of policy, regulatory, operational, safety, scientific, technical, international cooperation, and capacity building. The guidelines aim to provide support for space faring nations and entities on how to sustainably conduct space activities.

Already in the very beginning the guidelines refer, among other aspects, to the current developments of large constellations and increased risks of collisions of space objects, stating the need to address the associated risks by international cooperation. However, the concrete recommendations that are made to manage space debris stay mostly broad and do not prescribe any specific action, but merely point out the need for states and international institutions to establish appropriate rules, for example for space debris mitigation or the authorization and registration of space objects under their jurisdiction. So do the guidelines for example recommend states to adapt and revise their national legislation to better comply with international treaties and principles relevant to the long-term sustainability of space and to “implement space debris mitigation measures, such as the UNCOPUOS guidelines through applicable mechanisms”.

All in all, these guidelines do address several aspects which are important for space debris mitigation, especially considering small satellite technologies and applications. However, the guidelines don’t go much further than pointing out the issues and recommending actions to be taken and improvements to be made by states and international intergovernmental organizations. How exactly these actions and improvements should look like is not specified. These guidelines are rather laying out minimum standards that should be upheld and should ideally promote a change in the way space actors think about planning, authorizing and conducting space activities in the light of space sustainability (Martinez, 2022, p. 2598-2599). Consequently, these guidelines may at most be a first step in creating an international framework for space debris, but they do not contain any sort of reliable solution themselves and are rather a plea to space actors to cooperate and work towards solutions on their own.

2.3. Cooperation between Industry and Space Agencies

In comparison to the above-analyzed regulatory guidelines two selected recent documents from 2023 which were created by and in cooperation with space industry actors will be evaluated. These are, firstly, the Space Industry Debris Mitigation Recommendations of the World Economic Forum as recent and representative publication in this regard (**2.3.1.**), and, secondly, the ESA Zero Debris Charter (**2.3.2.**).

2.3.1. Space Industry Debris Mitigation Recommendations

The Space Industry Debris Mitigation Recommendations by the World Economic Forum were published in June 2023. The World Economic Forum, which is an international organization for public-private cooperation, drafted these recommendations in cooperation with the European Space Agency. The signatories of this document include some of the major private space actors, for example Airbus and OneWeb.

In the introduction of these recommendations, the risks and challenges of human-made space debris are acknowledged and in the light of the fast growth of the space industry sector, the growing risks associated with space debris shall be addressed. Their aim is to complement existing best practices and guidelines by setting realistic targets for behavior in orbit designed by a group of progressive industry actors. Moreover, the recommendations aim to support the establishment of a consensus in the space industry sector for the necessary conditions for its continued development. The recommendations contain six main points:

1. Post-mission disposal (PMD)
2. Collision avoidance, maneuverability and propulsion
3. Data sharing and traffic management in orbit
4. Financial measures
5. Environmental capacity
6. Responsibilities of governments

The recommendations provide in general more details and concrete targets than the above-assessed regulatory guidelines. For example for the post-mission disposal of space objects in LEO, it is recommended to strive for a success rate of 95-99% or above, for larger constellations it should be close to 99% or above. The time frame for the removal of a space object from LEO after the end of its mission time should be five years or less.

Also longer-term goals and requests of policy makers are included in this document. These include, firstly, the promotion of research on the environmental capacity of Earth's orbits in order to ensure a proper understanding of the overall population of objects in orbit, its evolution and the interaction between objects. Secondly, a plea to the responsibilities of governments is made with concrete suggestions as to what actions governments should take, like the creation of a legal obligation to remove launched objects from LEO within five years or less after the end of their mission time and consider active debris removal measures if necessary. Furthermore, the development of active debris removal technologies should be further promoted and supported, investments should be made into the development of automated space situational awareness measures, data sharing should be encouraged between spacecraft operators, space legislation should be coordinated and harmonized between governments, and the development and adoption of international standards should be supported.

The Space Industry Debris Mitigation Recommendations do not form as much of general debris mitigation guidelines with basic principles, like the avoidance of debris creation during missions, but instead rather focus on providing suggesting solutions for already problematic aspects. This includes the post-mission disposal time the potential necessity for more active debris removal capabilities the necessity for all spacecraft in a certain orbit to be maneuverable and the improvement of data sharing between spacecraft operators. Especially considering the express plea to governments, this document can thus be seen as a recommendation for regulators to make certain legal changes that are deemed necessary or beneficial by space industry actors in order to successfully manage the space debris issue. However, even if governments would not take such respective action, the recommended measures are detailed enough for space actors to be applied voluntarily and directly from this document. Regarding the content of these recommendations, several important aspects have been addressed in regard to debris risks of small satellites and constellations, for example the necessity for a particular high success rate of post-mission disposal missions when it comes to constellations and the generally shorter time limit for post-mission disposal, reflecting the shorter life span of smaller satellites, as well as the necessity for all spacecraft in a certain orbit to possess maneuverability, which is not yet given for all kinds of small satellites due to the simplicity of some models. All in all, this document provides valuable and important recommendations from which regulators should take inspiration and use their capabilities to promote similar measures through regulatory means.

2.3.2. ESA Zero Debris Charter

The ESA Zero Debris Charter, which was published in in November 2023, forms one of the most recent international actions on space debris and was created in collaboration with over 40 organizations from the space industry, including several major space actors like Airbus Defence and Space, Thales Alenia Space and OHB. This expressly non-legally binding charter aims to contribute towards space safety and sustainability and creates a common basis to work towards stopping the generation of space debris by 2030. For this purpose, the charter sets out three main guiding principles, which can be summarized as follows:

1. Minimizing the generation of new space debris
2. Anticipating and mitigating the adverse effects of space debris
3. Improving the knowledge and understanding of space debris and its impact

Considering these guiding principles, the charter sets out five targets for 2030, which should be collectively contributed to:

1. The probability of space debris generation through collisions and break-ups should remain below 1 in 1000 per object during the entire orbital lifetime. A suitable aggregate probability threshold for constellations of satellites in the low Earth orbit region should be identified.

2. Timely clearance of low Earth orbit and geostationary Earth orbit regions should be achieved with a probability of success of at least 99% after end of mission, including through external means when necessary.
3. The casualty risk from re-entering objects should remain significantly lower than 1 in 10,000, striving towards zero casualty. A suitable aggregate risk threshold for constellations of satellites in the low Earth orbit region should be identified.
4. Routine and transparent information sharing should be facilitated and active participation in strengthening global space traffic coordination mechanisms should be encouraged.
5. Access to timely and accurate data on space objects down to a size of 5 cm or smaller in low Earth orbit and 20 cm or smaller in geostationary Earth orbit should be improved to enhance decision making capabilities for collision avoidance.

Similar as the Space Industry Debris Mitigation Recommendations, this charter does not aim to be a general set of guidelines, but instead focuses on specific space debris related issues which need to be addressed and improved. It strives for a minimization of collisions or break-ups of spacecraft as well as of the casualty risk from re-entering objects, while mentioning the potential need for different risk thresholds for satellite constellations. Additionally, a high success rate of at least 99% for post-mission disposal is set as a goal, which would be in line with the respective recommendation for satellite constellations in the Space Industry Debris Mitigation Recommendations. Also, information sharing and tracking of very small space objects are important prerequisites for managing debris risks caused by small satellites in particular. In summary, the ESA Zero Debris Charter is not a set of guidelines but sets out certain concrete targets for improvement which fall into similar categories as some of the issue areas already pointed out in the Space Industry Debris Mitigation Recommendations. The charter can at the least function as an example of which issues to work towards, especially with the concrete numbers and thresholds designated in some parts of it.

2.4. Evaluation of the Currently Existing Legal Framework

In summary, only non-binding international regulatory instruments which specifically address space debris are currently available. While these do provide some important base guidance, they lack detail and leave the concrete actions to be taken by individual states or space actors. The documents on space debris published in cooperation with the industry provide more detailed and definite recommendations, often including defined thresholds and numbers. However, besides the fact that these documents are of no regulatory nature but merely voluntary and self-binding recommendations, they do also not cover all the necessary aspects needed for a satisfying and comprehensive legal framework on space debris as they focus more specifically on the currently most problematic aspects of space debris management. Consequently, neither of the assessed instruments provides a desirable legal framework for space debris management, but several points, especially from the more recent industry recommendations, may serve as valuable inspiration for a more comprehensive legal framework drafted by a regulatory authority.

The fact that no binding legislation regulating the handling of space debris exists is an issue, because non-binding instruments do not provide the same level of certainty of compliance due to their voluntary nature. Nevertheless, the above elaborated non-binding instruments may still provide some use to address the issue. On one side, they can serve as practical guidance for space actors and thereby factually influencing the conduction of space activities. On the other side, they may also have the potential to influence the political opinion in regard to space debris management and lead to further discussions and potentially more regulations in the future. Also on the level of national space law frameworks such non-binding instruments could serve as guidance and influence. They may also serve as a source of interpretation of the existing binding space law, like the Outer Space Treaty or the Liability Convention (Steinkogler, 2016, p. 226-227). Ultimately, the development of firstly unbinding principles and guidelines might be a starting point for the evolution of further rule sets in this area, comparable to the process of the development of international environmental law in the past (Hobe, 2023, p. 105).

Rules concerning space debris can be differentiated between measures serving to prevent the future generation of space debris and those addressing questions of responsibility or liability for created space debris (Hobe, 2023, p. 101). Conceivable are thus rules addressing the mitigation of space debris as well as rules addressing the handling of existing space debris, including its active removal. However, most currently existing rule sets focus only on the mitigation of space debris and clearer rules regarding responsibility and liability for the respective debris pieces and their active removal are still desirable, which is also reflected in the industry documents pointing out the need to further support the development of active debris removal measures and technologies.

In summary, the current international legal framework consisting of several non-binding sets of guidelines and recommendations does not form a satisfying and comprehensive solution for the space debris issue. Moreover, the regulatory instruments show particular deficiencies in comparison with instruments created in cooperation with industry actors, which have significantly more detailed and practically applicable recommendations.

3. POSSIBLE APPROACHES TO IMPROVE THE LEGAL FRAMEWORK

After establishing the insufficiency of the current legal framework in managing the space debris issue, the next step is to identify which approach should be taken in order to improve it. Firstly, it will be considered whether a new regulation on an international level is truly necessary, or if the solution to the issue could left for the level of national legislation (**3.1.**). Secondly, the question of the appropriate form of international legislation, particularly the possibility of concluding new binding international agreements on space debris, will be pondered (**3.2.**). Thirdly, it should be discussed whether a desirable legal framework on space debris might need also tailored content for emerging technologies like small satellites or whether the existing regulatory guidelines with their indifference to specific space objects is sufficient (**3.3.**). Afterward, two approaches other than the creation of new rule sets which are being discussed by scholars will be considered: The possibility of applying international environmental law principles to space (**3.4.**) and the creation of a new international authority which would dedicatedly be responsible for the management of space debris (**3.5.**).

3.1. Necessity of an International Solution

As the space treaties as well as the various space debris guidelines serve as a more general framework, the more concrete and detailed application of space debris mitigation measures will happen on the level of national jurisdictions. Accordingly, an approach could be to let national legislation solve the issue of space debris. However, the space debris issue is a global one which should be addressed in a unified way. By leaving it to individual national rules, the potential for significant discrepancies in the content of rules would arise. While one nation could enact strict debris mitigation measures, another nation could leave much more freedom to the operators of satellites. This could also lead to so-called “regulation shopping”, meaning that space actors could on purpose choose a jurisdiction with more favorable rules for them, or chain-of-custody issues where space activities are conducted across multiple jurisdictions (Martinez, 2022, p. 8). In the NewSpace age with private companies as a main space actor, this could result in the choice of jurisdictions with less strict debris mitigation requirements, as these usually are leading to more expenses. As a consequence, no effective comprehensive management of space debris would be feasible. For this reason, efficient and sufficiently concrete space debris rules need to be established on an international level.

Other authors suggest that the general legal framework for space activities under public international law as contained in the UN treaties is sufficiently general and flexible to enable and encourage states to carry out space activities in an orderly manner, while their national frameworks sufficiently specify the treaty obligations for the private sector to operate in a clear legal framework (Masson-Zwaan, 2016, p. 193). While this might arguably be true for the general space law framework, the space treaties do not sufficiently address the space debris issue to function as a legal base for further national law specifications. Consequently, a more detailed and pragmatic international solution is necessary to sufficiently address space debris.

3.2. New Binding International Agreements on Space Debris

An approach could be to conclude a new binding international agreement to regulate matters related to space debris. Already in the UN COPUOS Scientific and Technical Subcommittee conference 2021, the views were expressed that binding international standards as to space debris mitigation should be promoted (Report of the Scientific and Technical Subcommittee…, 2021). While binding international rules would arguably be the best possible baseline for managing space debris on a global level, the conclusion of an effective binding international agreement is likely not feasible in the near future. The negotiations for such an agreement would be assumingly lengthy and difficult, the more concrete the aspired rules would be the more difficult the finding of a consensus on the details and the wording would be. As a consequence, either more general, compromising and inefficient rules would be the result, or alternatively long and potentially unsuccessful negotiations would ensue. Neither of these alternatives would be ideal when it comes to finding ways to solve the current issue of space debris. Given the current increasingly competitive geopolitical environment between the major powers, the difficulty in concluding binding international agreements will, if anything, be further exacerbated (Freeland, 2019, p. 1321-1322).

Instead, non-binding instruments like guidelines might constitute a more promising solution. Due to their non-binding nature, the negotiations and finding of a consensus on the content of the recommendations are possibly more quickly. It is however important to not only create such guidelines isolated on a regulatory level, but to also consult with the private actors and the industry to create an acceptable ruleset for the actual space actors.

However, some scholars see the shifting focus from binding international agreements to soft law instruments as rather critical. It is brought up that only normative rules in the form of law instead of voluntary recommendations are capable of being concretely implemented and imposing responsibility and therefore consequences in case of their violation. While soft law offers more flexibility due to its non-binding nature, it is also not enforceable and might not always ensure the preservation of the interest of all countries, in particular of the weaker members of the space community (Hobe, 2023, p. 45).

Nevertheless, as long as comprehensive binding international agreements on space debris are likely not feasible in the near future, the improvement of non-binding instruments like guidelines and recommendations appears to be the best available option for regulators.

3.3. Specific Rules for New Satellite Technologies

Due to certain challenges when attempting to regulate new technologies, it should be discussed whether the emerging small satellite technologies should be expressly covered by an international legal framework on space debris or whether a more general approach is sufficient. Challenges in regulating new technologies are not exclusive to space technologies, as the evolution of technology brings always difficulties for lawmakers to fulfill their role of keeping a legal framework that ensures fairness, justice and safety (**3.3.1.**). In this context also the question arises in what ways the law should or should not try to steer or confine new technologies (**3.3.2.**). Subsequently, the implications for the specific regulation of small satellite technologies will be assessed (**3.3.3.**).

3.3.1. Technological Progress as a Legal Challenge

The progress of technological evolution causes several challenges to regulators and existing rules. A core issue when it comes to regulating new technologies is the so-called "pacing problem", which refers to the difficulty of regulatory oversight keeping pace with rapid scientific and technological innovation: While the pace for technological process is inherently rather high due to it being driven by private economic incentives and first-mover advantages, the governmental oversight is comparatively slow due to the necessary assessments and legal processes before a new set of rules can be put into place (Abbott, 2013, p. 3-5). Also often innovative activities or products, while they might take time to develop, rarely become visible to governments in time for governments to legislate before they are ready to emerge (Hutchison et al, 2017, p. 30).

A further issue for regulators lies in the difficulty of achieving a high quality of risk governance, as the technology to be regulated usually not only exists for one single use and purpose, but might touch a vast range of disciplines, like engineering, materials science, biotechnology or medicine, and might encompass numerous products or applications (Abbott, 2013, p. 6). In consequence, drafting an effective regulatory framework which precisely addresses the risks of a respective new technology while not overly hindering innovation is conceivably difficult, especially if the concrete implications and areas of use of a new technology are not always easily apparent and predictable.

A last point to be mentioned here is the problem of proper coordination of regulation of new technologies, in particular when a multiplicity of actors exercises regulatory authority, for example between the European Union and its member states (Abbott, 2013, p. 11). Moreover, new technologies will most likely not stay within the borders of one jurisdiction, but spread globally, which means that various unconnected jurisdictions worldwide will have to address the issue of drafting up legal frameworks, which might need substantially different ways of regulating one and the same technology, depending on which jurisdiction will be considered.

3.3.2. To What Extent Should New Technologies Be Regulated?

In particular with regard to the already above-mentioned aspect, that regulation might hinder technological evolution or the effective use of certain applications, a question that should be addressed in more detail is to what extent new technologies should even be regulated.

Subjecting any new technologies immediately to regulations might temporarily prevent the realization of potential risks lying in such technologies, however, it also might prevent later positive effects it might have by restricting its free development. On the other hand, a certain deceleration of the technological development process to create a creative delay, discussion space and the possibility to take all stakeholders on board, which legal restrictions could provide, could make such a delay well worth it (Drechsler, Kostakis, 2014, p. 128-130). Moreover, if technological developments are allowed to fully run free, the fast-paced progress driven by free market interests might not be the most desirable way, as such monetary-focused developments, often controlled by industry lobbyism, might not always be in the best interest of society as a whole.

Hence, it could be argued that before changing our laws according to the technologies that currently define our lives, it is important to have a discussion space, not least to allow for social struggles to take place. If at a given time, the law codifies, embodies, and crystallizes elements of the past, it simultaneously creates the conditions for its enhancement or even for radical reformation (Drechsler, Kostakis, 2014, p. 128-130).

3.3.3. Implications for Small Satellite Technologies

In light of the above, there can be inferred three main points for the regulation of technologies: Firstly, it is a difficult task for regulators to keep up with technological advancements. Secondly, regulation does not always have to be enacted immediately when a new technology emerges, as that might obstruct innovation while the newly arising legal issue could already be solved through interpretation of the existing laws. Thirdly, if done with the right "dose", a regulation may also promote the development and application of new technologies while minimizing the risks it might pose to society.

When it comes to small satellite technologies, a certain amount of regulation might thus be beneficial. Considering the age of the space treaties and the specific issues that the emergence of small satellites could bring to the space debris issue, it seems necessary to create also specific rules to address these issues. Attempting to regulate this twenty-first-century technology solely by reference to twentieth-century rules, devised for other space systems and technologies, is likely to create difficulties and uncertainties and perhaps deter some who would otherwise consider engaging in these new space industries and space-based services. The international regulatory framework was neither designed to deal with the advent of this technology nor for the expansive range of new space actors (Freeland, 2019, p. 1332-1333).

On the other hand, some scholars suggest that the issues might not be as severe as expected and thus no new regulation might be necessary. In particular, the possibility is mentioned that many of the proposed satellite systems will not be able to obtain the needed financing to build and launch them, leading to much fewer satellites and constellations actually ending up in space than proposed and estimated. For instance, in the 1980s, the US Federal Communications Commission actually approved licenses for 17 new Ka-band satellite systems to be deployed. Ultimately however, only two of those systems were in fact launched and operationally deployed (Pelton, Madry, 2020, p. 25). Although with the current numbers of expected satellites to be launched reaching up to several thousand for a single constellation, it seems careless to rely on the possibility that so many of these might not be launched that no additional space debris issues arise. Especially considering companies like SpaceX, which are regularly launching around 20 new satellites for their constellations every week (SpaceX Launches, 2023).

However, it will be important to not "overregulate" and hinder technological development. One of the biggest issues will be how to fit the new technology of small satellites into the existing space environment; control of space debris and safety of satellite traffic are essential for the success of this change in technology (Larsen, 2017, p. 308). Especially as the further evolution of small satellite technologies might be a key factor in finding solutions to the space debris issues, either by improved technical capacities of small satellites allowing them to perform mitigation maneuvers, by longer lifetimes of the satellites, or by active debris removal measures being conducted by small satellites. New rules for small satellites should therefore be considered, but in a way that promotes technological progress. A similar view was also expressed by some delegations in the 2023 session of the UNCOPUOS, where it was stated that considering the essential role of satellites, regardless of their size, in the socioeconomic development of Member States, the Committee and its Subcommittees should not create an ad hoc legal regime or any other mechanisms that might impose limitations on the design, construction, launch and use of satellites (Report of the Committee…, 2023, p. 30). However, with no limitations at all it is questionable whether an effective framework for space debris management could be created. Accordingly, some limitations, for example for the number of launches or active satellites or minimum requirements for technical capabilities of satellites should be considered.

In summary, despite the challenges that the regulation of evolving technologies entails, specific rules for small satellite technologies should be considered in a legal framework on space debris. Not only to more appropriately cover the peculiarities of small satellites which lead to a higher risk of space debris generation, but also to steer the development and application of small satellite technologies in order to proactively mitigate their risks for the future.

3.4. Application of International Environmental Law Principles to Space

Another discussed approach to tackle the space debris issue outside of creating a dedicated legal framework includes the application of the already established principles of international environmental law to space, in particular the precautionary and prevention principles, as well as the polluter-pays principle (Chowdhury, 2022, p. 106-109). As these principles aim to manage pollution on Earth, a similar effectiveness for managing pollution in space could be conceivable. An advantage of these principles is that they are already internationally recognized and understood, thus they might have a higher acceptance and application rate than a newly drafted set of rules, while also being available already now and not causing further timely delay due to negotiation and drafting processes.

In particular, the precautionary principle could be of relevance. This principle states that precautionary measures have to be taken whenever an activity seriously threatens or causes irreversible damage to human health or the environment even if the adverse effects have not been fully established scientifically. For the application of this principle could, for example, a threshold or benchmark for the permissible creation of space debris be agreed on internationally. Any creation of space debris beyond that threshold would be in violation of the precautionary principle (Chowdhury, 2022, p. 107). Additionally, a reversal of the burden of proof could be interpreted from the precautionary principle, meaning the satellite operator has to prove that their actions are in line with the principle (Nair, 2017, p. 71).

A second relevant principle could be the polluter-pays principle, which has been internationally accepted and applied for many years (Trail Smelter Arbitration, 1941), imposes the liability for the effects of a polluting activity on the polluter. With this principle, the actor causing new space debris would also be liable to remove it, or liable for any further damage caused by that debris. However, this might be impractical in reality as it is often difficult to attribute small debris pieces to one specific originator, and the exact effects and damages one debris piece causes are likewise difficult to attribute. The polluter-pays principle could nevertheless be used to create a fee for each launch reflecting the average amount of debris created. The means created through this fee could then be used to fund the removal of space debris (Chowdhury, 2022, p. 109).

At least some of the international environmental law principles could therefore be fittingly applied in space. The question is, however, if that is a solution on its own. Taking precautionary measures regarding the creation of new space debris is already the focus point of most of the legal instruments and guidelines addressing debris mitigation. How exactly this precaution should be executed would still be up for an international agreement, leaving the application of this principle without much-added benefit. Likewise, while the idea behind the polluter-pays principle is sound, it is likely not disputed anyway that the actor responsible for space debris should be the first option to be liable for its consequences. The problem lies again in the further detail: How to attribute specific debris pieces to individual actors? How to determine which debris piece caused exactly which damage? These questions will likely also not be answered by the application of the polluter-pays principle. In summary, these principles could be applied to space as well and they might function as a supplementary set of guidance, however the additional discussions and clarifications that would be needed on an international level would not make the application of these principles a better option than creating a new, tailored international legal framework for space debris.

3.5. Creation of a New International Authority for Space Debris

A last approach that will be evaluated here is a proposal made by scholars to create a new international authority or organization which should dedicatedly deal with the management of space debris (Sheer et al., 2023, p. 2623-2625; Larsen, 2018, p. 518). Such an authority could function as a global central coordination point for space debris mitigation and removal and potentially improve the application of space debris related rules and principles and create clarity regarding processes and definitions of space debris management on an international level.

However, as of now no signs or concrete discussion regarding the creation of such an international authority are apparent. Further it would be questionable if the creation of such an authority would be an actual solution to the current space debris issue. For an international authority to be effective, it would need to be equipped with the necessary competencies to regulate matters concerning to space debris and be accepted by the major space-faring countries. The question is whether a consensus on an international level could be found in this regard. The agreement necessary for the creation of such an authority would be likely comparable to the conclusion of a binding international agreement on space debris, which is likely not feasible in the near future (see above **3.2.**). Thus, even if an international authority for the management of space debris could provide benefits, the pursuit of it seems not like a practical next step in trying to find a solution for the space debris issues in the short term. Consequently, focusing first on improving the international legal framework on space debris stays as of now the sensible approach.

4. PROPOSALS FOR REGULATORY ACTION

To improve the international legal framework on space debris particular regard has to be paid to the implications the emergence of small satellites has brought. In light of the assessments made above, the following two main points are proposed in order to create an improved international legal framework on space debris: Firstly, the current debris mitigation rules should be revised to cover their inadequacies regarding the peculiarities of small satellites (**4.1.**). Secondly, a legal framework for active debris removal should be set up for the cases in which debris mitigation is not sufficient (**4.2.**).

4.1. Revision of Debris Mitigation Rules

The currently existing space debris mitigation rules, in particular the Space Debris Mitigation Guidelines of the UN but also to an extent binding international agreements, should be revised to more appropriately cover the specific issues that small satellites bring. This includes the addition of binding definitions of the key terms and concepts related to space debris (**4.1.1.**), a limitation on the number of active satellites per space actor (**4.1.2.**), a shortening of the recommended post-mission disposal timeframe (**4.1.3.**), as well as an adaptation of the rules for registration (**4.1.4.**) as well as for authorization and supervision of space objects (**4.1.5.**).

4.1.1. Binding Definitions

The clarity of a rule fundamentally depends on whether all its words are clearly understood and leave no room for misinterpretation, ideally through definitions in the text of the rule itself. Thus, the most important terms should be clearly and ideally bindingly defined, in particular the terms “space debris” and “small satellite”. Already at this basic starting point, the international framework is currently lacking. In the binding space treaties, the term “satellite” is neither used nor defined, instead the texts refer to the term “objects” or “space objects”. Beyond that, there is consequently also no definition of what qualifies as a “small satellite” (see also above **1.2.**). Also neither any form of satellite “constellation” is defined.

Moreover, the term “space debris” is not defined in any binding and definitive way. While the IADC Guidelines and on their basis also the UN Guidelines on Space Debris Mitigation included a definition of space debris, these instruments are expressly non-binding. While soft law instruments are easier to adopt and more flexible than binding international agreements, they also might accordingly lack in their extent of implementation. Without a clear definition, each regulating body might to some degree regulate different matters with different scopes, excluding any chance for an internationally met standard. In particular with regard to the specific challenges small satellites and satellite constellations bring to the mitigation of space debris, a dedicated definition would allow to impose more tailored requirements on them.

Clarifying and defining relevant key legal concepts, like “space debris”, “active removal” or “small satellite” could create a solid legal basis for subsequent specific mechanisms (Yang, Wu, 2022, p. 2612). This could be done via binding agreement only on the respective definitions, which might be more feasible than elaborate space debris agreements, or via UN resolution, setting internationally accepted definitions of the most important terms and concepts, and subsequently improving harmonization of further guidelines set up on any other regulatory level.

Additionally, there exist discussions on whether a piece of space debris also falls under the definition of “space object” as indicated in the Outer Space Treaty and the Liability Convention (Sheer et al, 2023, p. 2618). As these two conventions do not contain any precise definition of space object and do further not contain any indications that only functional man-made objects should be covered by this term, some scholars assume that space debris falls under this qualification of “space object” (Tian, 2019, p. 120; Steinkogler, 2016, p. 213). If so, then damage caused by space debris would fall under the scope of the Liability convention with the corresponding consequences. If space debris would not be qualified as a “space object” in that sense, then instead general international mechanisms for damage remediation would need to be used. Thus, a binding definition which would clarify whether or not space debris also qualifies as a “space object” would be of importance.

When it comes to thinking of a conceivable definition, a satellite could be defined as a “space object enabling space applications like observation, communication, navigation and other support functions” (Nair, 2019, p. 64-65). To distinguish it from space stations it could be added that it should be an “unmanned” space object. Furthermore, it could be added that a satellite is orbiting Earth at a specific distance, i.e. in one of the recognized orbital zones, like LEO or GEO. A further definition specifically for “small” satellites could include a certain mass threshold, like used in varying levels by current definitions of different institutions. Additionally, some of the main distinguishing factors to bigger satellites could be included, for example the almost exclusive use in LEO, whereas bigger satellites are often also used in GEO. Furthermore, small satellites are often used in large numbers in a constellation and are more flexible in their equipment and type of use (Nair, 2019, p. 65).

How the definitions would be phrased in detail is however secondary, important is an agreement on internationally unified definitions.

4.1.2. Limited Number of Active Satellites

Currently there are no limitations or recommendations on the number of active satellites that each state or space actor may launch into orbit. During the last few years, the number of launches has increased significantly. In the year 2022, there were 186 rocket launches conducted, 72 more than in the year 2020 (2022 Orbital Launches Year in Review; 2020 Orbital Launches Year in Review). This trend will likely continue considering the large dimensions of the various planned satellite constellations. Additionally to the higher replacement rate of small satellites due to their shorter mission time, some satellite operators might also account for redundancy and launch even more satellites than necessary to cover for potential faults in individual satellites of the constellation (Freeland, 2019, p. 1330). For constellations of small satellites which consist of up to thousands of satellites, there are accordingly more launches to deliver all these satellites into orbit. And it needs to be considered that each launch creates more space debris, even without any collisions or malfunctions as some rockets or launch vehicles are to some degree reusable, most others usually leave parts, or "stages", of them behind in orbit, creating new space debris.

Moreover, while the number of satellites each space actor may have active is unlimited, the actual space in orbit is not. The orbital slots in GEO, which is due to the necessary positioning of the satellites an even more limited orbit than LEO, have already been declared by the International Telecommunication Union ("**ITU**") as a limited natural resource and requiring specific authorization for their use. While the LEO, in which most small satellites are being used, is not as limited as the GEO as the satellites do not need to stay in one specific spot relative to Earth's surface, the amount of space is nevertheless not infinite. The large number of satellites launched may even render the LEO overcrowded and exceed the carrying capacity of orbit, which would limit further space activities in this region (Yang, Wu, 2022, p. 2608; Braun, 2020, p. 275-277). Nevertheless, the possibility of using an orbital slot allocation system also in LEO could be conceivable (Arnas et al., 2020). As well it could be considered to declare orbital slots in LEO as a limited natural resource (Nair, 2017, p. 71). At the very least, the more objects are in the same orbit, the higher the chance for collisions and the more difficult will be the deployment of more satellites in the same orbit in the future. And as long as there exists no limitation on the number of satellites, the currently dominant space actors could just continue to deploy more and more satellites to occupy as much space for themselves as possible. In a sort of "space race", this could disadvantage currently developing space actors and countries, which do not yet have the capacities to use orbital slots and which in the future will have more issues when the LEO is already filled with a high density of other space objects.

Accordingly, even if it could be a rather drastic step and accordingly questionable if an agreement on an international level could be found, a limitation to the number of active satellites per space actor in some shape or form could be considered for an international space law framework on space debris. Its implementation could, for example, work similarly to the orbital slot allocation in GEO, in that an international authority like the ITU manages and allocates the orbital slots to a set of predetermined rules which allow for a fair distribution of the space in GEO while also not overburdening the available space.

4.1.3. Shorter Post-Mission Disposal Timeframe

A common recommendation in the international guidelines is the removal of satellites after at most 25 years after the end of their mission time. However, this time limit was established having in mind older satellite models, which were designed to stay in orbit for potentially decades. With the current trend of small satellites which are often only intended to be in orbit for up to a few years to enable a more rapid technology refresh, the removal of satellites based on a 25-year cycle is no longer suitable (Pelton, Madry, 2020, p. 27-28; Muelhaupt et al., 2019, p. 86). Leaving the 25-year rule would mean that large numbers of satellites would stay much longer in orbit than needed, which is especially problematic with the high replacement rate of small satellites in large constellations.

As a consequence, the US Federal Communications Commission ("**FCC**") (FCC approves new orbital debris rule, 2023) as well as the Space Industry Debris Mitigation Recommendations by the World Economic Forum as of recent recommend instead a shorter post-mission disposal timeframe of five years. It should be strived for an establishment of this shorter timeframe also on the UN level in order to push for a globally accepted standard.

Additionally, it should be considered to establish specific rules for large satellite constellations. This was also acknowledged in a statement by the IADC in 2021, where it was stated that the 25-year post-mission disposal time limit might need to be reduced to address the large number of satellites in the increasingly popular constellations, however without specifying any concrete time frames (IADC Statement on Large Constellations…, 2021). In particular when individual satellites of a constellation are to be replaced, the old satellite should be required to be removed from its orbit as soon as possible after its replacement has been launched regardless of the 5-year time frame. With the expectation of several thousand new satellites to be launched in the upcoming years, the prompt removal of non-functioning satellites has to be a focus point to limit the already high impact of the large number of new satellites.

4.1.4. Registration of Small Satellites and Constellations

To ensure clear conditions regarding jurisdiction and control of a specific state over space objects, international space law requires every space object to be registered (Marboe, 2016, p. 10). Next to several UN resolutions, the Registration Convention constitutes the most important international legal source for the registration of space objects. The Registration Convention stipulates in its Art. II that the State of Registry is to maintain a national register in which such space objects are to be included and, in addition, shall provide certain specified information in relation to those objects to the UN, which itself maintains a central register. The State of Registry can, according to Art. I Registration Convention and Art. I Liability Convention, be the launching state, which is the state that launches or procures the launch of a space object or from whose territory or facility a space object is launched. In case of cooperation of several states in a launch, these states have to agree between themselves on which will be registered as the launching state, as this can only be one.

An issue for small satellites might be that satellites will often be operated by private entities and launched from abroad. This will raise the question of whether the state where the private operator is located will consider itself as a launching state, for example as a state "procuring" the launch"; otherwise, this specific satellite might not be registered at all (Masson-Zwaan, 2016, p. 178).

A further issue concerning the registration of a satellite under the Registration Convention arises in the context of satellite constellations, as the registration process thereunder is tailored for the registration of individual space objects (Lyall, Larsen, 2018, p. 242). Under the current framework of the Registration Convention, each satellite would have to be registered individually, which would pose a significant formal effort. Furthermore, small satellites have a shorter mission, sometimes until a few months, which necessitates a fast and efficient registration and de-registration process to achieve a reliable register. Such a register of all the objects in orbit is of significant importance when it comes to tracking the individual objects to avoid collisions, and also to attribute them to a liable actor. In light of the current trend towards using small satellites in large constellations, a specific constellation register could be considered as well (Yang, Wu, 2022, p. 2613).

In any case however, the rules on the registration of space objects should be adjusted, for example through a clarification in a UN resolution, to be more suitable and practical for potentially large numbers of small satellites with a relatively short lifespan.

4.1.5. Authorization and Supervision

One of the main space law obligations of states concerns the authorization and supervision of space objects launched under their respective jurisdiction. This follows from Art.VI of the Outer Space Treaty, which states that the respective state parties to the OST shall bear international responsibility for national activities in outer space, regardless of whether these are conducted by state or by private entities, and that such activities of non-governmental entities in outer space shall require authorization and continuing supervision by the appropriate State Party to the OST.

An important aspect of the authorization and supervision concerns the enforcement of liability. The general basis of liability rules in space law can be found in Art. VII OST, which states that a state party which launches or procures the launching of an object into outer space and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another state party to the OST or to its natural or juridical persons by such object or its component parts on the Earth, in air or in outer space, including the moon and other celestial bodies, or in short, the launching state is liable for any damage caused by the launched space object. This general imposition of liability is further concretized in the Liability Convention, which foresees a liability for the launching state of a space object and differentiates in its articles II and III between absolute liability for damage caused on Earth and to objects in flight and fault-based liability for damages caused elsewhere. However, even if it is not a State Party to the Liability Convention, a State would still be subject to the liability provisions in the Outer Space Treaty, as well as any other potential claims under relevant general principles of public international law (Freeland, 2019, p. 1325). In case of such a collision in outer space, it would need to be established if the launching state was at fault. What degree of care is necessary in outer space is difficult to determine, as no space traffic management rules exist as of now. Moreover, the term “fault” is not defined in the liability convention, which means also international standards and guidelines on debris mitigation might be used as a basis for interpretation of what constitutes a “fault”, in particular when they are followed by most spacefaring nations (Capurso et al., 2023, 443; Steinkogler, 2016, p. 231). In case actions go against such international standards and guidelines, it could be argued that these fulfill the notion of being at "fault". As a practical issue, it might often be difficult for the applicant of a damage claim to prove that the other party was at fault, for example that the other party was not complying with international standards and guidelines on space debris mitigation. A suggested solution by some scholars would be a reversal of the burden of proof, or a presumption of fault for each party's own conduct unless the respective party can prove that it complied with the applicable standards of diligence (Capurso et al., 2023, p. 445).

It is generally accepted that also small satellites constitute space objects, meaning their use falls in the scope of this Art. VI OST and needs to be authorized and supervised accordingly (Freeland, 2019, p. 1323; Von der Dunk, 2016, p. 158). This is particularly relevant, as not only big players, like states or large corporations have the possibility to use such small satellite technology, but the more accessible small satellite technologies might be used by parties on an amateur level, for example private "hobby" researchers or university students, who are not even aware of the need for registration. However, as the OST does not define what an "activity in outer space" is, some room remains for the argument that not all phases of the small satellite's lifetime need authorization and supervision, in particular concerning the in-orbit phase (Marboe, 2016, p. 6). Typically, the authorization of space activities is implemented by way of a licensing regime established under national law (Freeland, 2019, p. 1323). If, however, no national space legislation exists which foresees authorization obligations, space activities may be initiated by private entities without any such authorization. In that case, the respective state may thus be not informed about the space activity but is nevertheless responsible (Marboe, 2016, p. 7). The situation might also arise, that the respective state authority was not informed of the launch of the space object, as the operators of the small satellites might not always be aware of such legal requirements as some of them may deem their activities rather as "amateur" activities (Steinkogler, 2016, p. 232; Marboe, 2016, p. 3).

Furthermore, there might be cases when an operator does not receive authorization from the competent authority but decides to launch their satellites regardless. So did the US startup "Swarm" launch four nanosatellites via an Indian Polar Satellite launch vehicle without the necessary authorization by the US FCC, which resulted in a penal payment of $ 900,000 by the startup (FCC issues warning…, 2018). Without authorization, there is also no possibility to track or enforce the application of debris mitigation measures. However, even with authorization it is important for the supervision authority to supervise and enforce if necessary debris mitigation measures. In 2023 the FCC issued the first ever fine for the failure of a satellite operator to comply with debris mitigation measures (Dish Is First Company to Be Fined…, 2023). The company "Dish" failed to move one of its satellites into a ”graveyard orbit” above LEO after the end of its authorized mission time and consequently received a fine in the amount of $ 150,000 and had to ensure the prevention of any further such incidents.

Furthermore, in such cases of satellite launches without authorization, the state might be not willing to accept liability for small satellite activities which are in principle in their jurisdiction, but the state might be held liable nevertheless if fault for damage caused by a small satellite activity can be established (Steinkogler, 2016, p. 232). This situation would accordingly also pose problems when trying to identify the cause and liable actor of an event creating space debris, for example if a satellite collides with another or does not de-orbit at the end of its mission time. If, however, a satellite was authorized even though its operating scheme is not compatible with international technical standards and good practices, including space debris mitigation standards, the fault of the respective launching state could be potentially established (Marboe, 2016, p. 8). However, when it actually comes to a collision with a piece of debris it might be doubtful realistically whether an attribution of pieces of debris which may be as small as 1 cm and still have an immense destructive power can successfully be undertaken to determine a liable state (Hobe, 2023, p. 101).

Another issue is that still many small satellites do not possess control systems which would allow them to maneuver once they are launched and operative, meaning their position can not be altered from Earth as soon as they are placed in orbit (Freeland, 2019, p. 1324). This would apply especially to amateur projects or satellites of developing space actors which might not yet have the newest technologies available and rely on the affordability of small satellites. Consequently, these types of small satellites are not able to evade other objects that might cross their orbital path, which increases the risk of collision and following destruction, leading to the further creation of space debris. To highlight this issue, the satellites of SpaceX's Starlink constellation had to perform by now over 50,000 avoidance maneuvers since their launch in 2019 (SpaceX Starlink satellites had to make…, 2023). Additionally, with the lack of a propulsion system or any other way to maneuver the satellite, the post-mission disposal possibilities are limited as well. This factor makes also effective supervision more difficult, as the operator of such a small satellite might not even be able to control it to follow any potential orders of the supervisory authority.

Consequently, the rules and requirements for the authorization and supervision of small satellites should be revised to address these above-mentioned issues. In concrete terms, it should be recommended that every satellite operator needs to provide a debris mitigation plan to receive authorization, in particular concerning satellite constellations.

Furthermore, some sort of maneuver or control capabilities of the satellite should be a requirement to receive authorization as well. It should also be considered to recommend to authorities the strict enforcement of debris mitigation measures as described in the respective authorization.

4.2. Creation of a Legal Framework for Active Debris Removal

While space debris mitigation is an important aspect of managing the amount of space debris, it is not always possible to fully mitigate the creation of new debris, for example due to technical limitations in rocket or satellite design, or due to unintended collisions of space objects. Even if a very high level of compliance would be given for the UN Space Debris Mitigation Guidelines, this would still not be sufficient to overturn the existing negative trends in orbital pollution and therefore additional remediation measures must take place (Hobe, 2023, p. 227; Larsen, 2018, p. 494). In particular small satellites in large numbers could still cause an exponential growth of the debris population despite compliance with current debris mitigation measures (Virgili, Krag, 2015, p. 8). This assumption is also supported by the ESA Space Environment Report of 2023, which not only lays out that the current level of compliance with debris mitigation rules is too low for a sustainable space environment, but also indicates that even without any further launches the debris population will increase due to collisions of already existing debris pieces among each other (ESA's Annual Space Environment Report, 2023, p. 8). Consequently, the concept of active debris removal will inevitably play an important role in the future and should be steered and promoted through effective regulation.

However, drafting a legal framework for active debris removal ("**ADR**") poses several issues that need to be addressed. Firstly, ADR is premised on the innovative development of relevant technologies (Yang, Wu, 2022, p. 2612). Without feasible and practically effective and affordable technical solutions to conduct ADR, a framework to regulate it could be premature. While small satellites are a factor in the increase of space debris, they also could provide technical solutions to actively remove debris (Steinkogler, 2016, p. 232). Already several years ago methods for the removal of space debris by utilization of small satellites were researched, for example by using an electro-dynamic tether technology to lower the orbits of space objects (Nishida et al., 2009). Some of the more recent approaches include for example the use of satellite constellations to track space debris (Satellite swarm to provide "missing link"…, 2023; ESA funds study to tackle space debris…, 2023). Even if the technical capacities for ADR are still in development, preparing a general legal framework for it would be an important step considering that the market size for ADR methods like on-orbit servicing is already now increasing steeply (Global On-Orbit Satellite Servicing Market…, 2023). The law currently still has the chance to be not just reactionary, but to steer and promote the development and application of ADR measures. A legal framework could even foster the development of ADR technologies and attract the creation of start-ups in the field.

Some authors bring up the issue, that ADR could go contrary to the principle of non-retroactivity, as now satellite operators might need to find ways to actively remove their satellites even though there was no such obligation when their satellite was launched (Yang, Wu, 2022, p. 2611). This should, however, not be a fundamental issue. Satellite operators already today should follow the various debris mitigation guidelines, which usually require removing the satellite from orbit after its mission is finished. If a satellite does not have such capabilities to do so on its own, it would be expected for the operators to remove it actively by external means.

To create an effective legal framework for ADR which manages these issues, clear rules who may remove which debris object under which circumstances need to be laid out. First of all, it should be established who should remove a specific piece of debris. As a starting point, this should ideally be the actor who was responsible for the creation of this debris piece. More complicated, however, is the removal of debris by third parties. As each piece of space debris has at some point been launched as a functioning space object or part thereof, such piece falls under Art. VIII OST, which stipulates that the state of registry shall contain jurisdiction and control over this object while in outer space. Thus, it needs to be clarified if or when this debris piece may be removed by other actors without infringing the original operator's jurisdictional or control rights (Chung, 2020, p. 45-46).

As a second point, it needs to be established which specific debris pieces are to be removed, or if just a general quota of the existing debris is up for removal. In this context also a binding definition of space debris is again of importance, as there might be debates about when exactly a space object becomes removable "space debris".

Thirdly, the circumstances of the removal need to be set out. This includes the method of active debris removal, which should be an internationally approved one. Moreover, the costs and the liability of potential damages occurring during the removal mission should be addressed. For this purpose, a clear standard for the conduction of ADR could be established as a criterion to determine whether a certain level of due diligence has been fulfilled, which would exclude the liability for any damages resulting from such diligent ADR measure (Tian, 2019, p. 127). Furthermore, it needs to be established when an active debris removal mission should be conducted. Conceivable would be a model, in which an ADR mission needs to be initiated whenever the debris mitigation measures of a satellite fail, for example, if a satellite due to technical failure does not de-orbit as planned after the end of its mission time. In such a case, this satellite could be designated for an ADR mission, which costs could be borne by the operator or owner of this satellite as the liable actor. Thinking one step further, mandatory insurance to cover the ADR costs could be included in the legal framework.

One the other side, there should be incentives created for ADR operators to conduct such missions and to promote the development of ADR possibilities and capacities. This is particularly important as there is currently a lack of prospects of short-term cost-effective returns due to the still low demand and expensive technical requirements (Tian, 2019, p. 113). Such incentives could include the covering of the costs of ADR, which could be done either by the liable actor of the removed debris piece, or by an international ADR fund (Tian, 2019, p. 123). Such a fund could be created by charging a certain fee per launch or active satellite, which would fittingly be used to remedy the average amount of newly created space debris for a respective launch (Sheer et al, 2023, p. 2622). It is however important, that such a fee would not restrain progress by making the business economically unsustainable for actors. According to a study, it is in general conceivable for launches to be economically feasible even with such a fee (Bernhard et al., 2023, p. 28-29). Additional incentives could be given by allowing launches dedicated to ADR missions to receive prioritized treatment in the authorization or registration processes, or provide subsidies for the launch costs.

CONCLUSIONS AND PROPOSALS

1. The current international space law framework addressing space debris exists only in a fragmented manner over various legal instruments, with no binding rule sets but instead only non-binding guidelines and recommendations being available.
2. This existing legal framework is not sufficient, as several aspects are not addressed in sufficient detail and not suiting to the peculiar issues the emerging trends of using small satellites bring for the space debris issue.
3. The currently most promising approach to address the space debris issue by legal means is to create a mostly non-binding international legal framework specifically concerning space debris while considering the particularities of small satellites.
4. In order to create a desirable and sufficient legal framework it is, therefore, proposed to revise the existing international debris mitigation rules and recommendations. While it will realistically not be possible to find agreements in the international community on all the currently lacking aspects of the legal framework on debris mitigation, their consideration and discussion are nevertheless important to further advance the development of a desirable legal framework.
5. In addition, an international legal framework for active debris removal should be established. While the necessary technologies are currently still in an early stage, the concept of active debris removal will be paramount in managing the population and associated risks of space debris in the long term. Promoting and steering the development of active debris removal missions through legal instruments will be an important next step for the future of human space activities.

LIST OF REFERENCES

Legal Acts

International Legal Acts:

1. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979). 1363 UNTS 3.
2. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968). 672 UNTS 119.
3. Convention on International Liability for Damage Caused by Space Objects (1972). 961 UNTS 187.
4. Convention on the Registration of Objects Launched into Outer Space (1975). 1023 UNTS 15.
5. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial bodies (1967). 610 UNTS 205.
6. United Nations General Assembly Resolution - 62/217. International cooperation in the peaceful uses of outer space (2007). A/RES/62/217.

Regulatory International Guidelines and Recommendations

7. Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (2010).
8. Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space (2019). A/74/20 Annex II.

Special Literature

Printed Monographies:

9. Abbott, K. W. (2013). The Challenge of Oversight for Emerging Technologies: Introduction. In: Marchant, G. E., Abbott, K.W., Allenby B. (eds.) (2013). *Innovative Governance Models for Emerging Technologies*. Edward Elgar Publishing 2013, 1-16, https://doi.org/10.4337/9781782545644.00006.
10. Baker, H. A. (1989). *Space debris: Legal and policy Implications*. Boston: Martinus Nijhoff.
11. Braun, V. (2020). Small Satellite Constellations and End-of-Life Deorbit Consideration. In: Pelton, J. N. (ed.) (2020). *Handbook of Small Satellites*.

Cham: Springer Nature Switzerland AG, 259-281, https://doi.org/10.1007/978-3-030-36308-6_13.

12. Chung, G. (2020). Jurisdiction and Control Aspects of Space Debris Removal. In: Froehlich, A. (ed.) (2019). *Space Security and Legal Aspects of Active Debris Removal*. Cham: Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-319-90338-5_3.
13. Freeland, S. (2019). Legal Issues Related to the Future Advent of Small Satellite Constellations. In: Pelton, J. N. (ed.) (2020). *Handbook of Small Satellites*. Cham: Springer Nature Switzerland AG, 1315-1336, https://doi.org/10.1007/978-3-030-36308-6_73.
14. Hobe, S. (2023). *Space Law*. Second Edition. Baden-Baden: Nomos Verlagsgesellschaft mbH & Co. KG.
15. Lyall, F. and Larsen, P. B. (2018). *Space Law – A Treatise*. Second Edition. Abingdon; New York: Routledge.
16. Marboe, I. (2016). Small Is Beautiful? Legal Challenges of Small Satellites. In: Sterns, P.M., Tennen, L.I. (eds.) (2016). *Private Law, Public Law, Metalaw and Public Policy in Space, Space Regulations Library 8*. Springer International Publishing Switzerland, 1-16, https://doi.org/10.1007/978-3-319-27087-6_1.
17. Masson-Zwaan, T. (2016). Registration of Small Satellites and the Case of the Netherlands. In: Marboe, I. (ed.) (2016). *Small Satellites: Regulatory Challenges and Chances*. Brill Nijhoff 2016, 174-194.
18. Nair, K. K. (2019). *Small Satellites and Sustainable Development – Solutions in International Space Law*. Cham: Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-030-18620-3.
19. Pelton, J.N. and Finkleman, D. (2020). Overview of Small Satellite Technology and Systems Design. In: Pelton, J. N. (ed.) (2020). *Handbook of Small Satellites*. Cham: Springer Nature Switzerland AG, 125-144, https://doi.org/10.1007/978-3-030-36308-6_7.
20. Pelton, J. N. and Madry, S. (2020). Introduction to the Small Satellite Revolution and Its Many Implications. In: Pelton, J. N. (ed.) (2020). *Handbook of Small Satellites*. Cham: Springer Nature Switzerland AG, 1-29, https://doi.org/10.1007/978-3-030-20707-6_1-2.
21. Tian, Z. (2019). Proposal for an International Agreement on Active Debris Removal. In: Froehlich, A. (ed.) (2019). *Space Security and Legal Aspects*

of Active Debris Removal. Cham: Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-319-90338-5_7.

22. Von der Dunk, F. (2016). Liability for Damage Caused by Small Satellites – A Non-issue? In: Marboe, I. (ed.) (2016). *Small Satellites: Regulatory Challenges and Chances*. Brill Nijhoff 2016, 154-173, https://doi.org/10.1163/9789004312234_010.
23. Steinkogler, C. (2016). Small Satellites and Space Debris Mitigation. In: Marboe, I. (ed.) (2016). *Small Satellites: Regulatory Challenges and Chances*. Brill Nijhoff 2016, 211-236, https://doi.org/10.1163/9789004312234_013.

Articles:

24. Arnas, D., Lifson, M., Linares, R. and Avendano, M. E. (2020). Definition of Low Earth Orbit slotting architectures using 2D lattice flower constellations. Advances in Space Research, 67, 3696-3711, https://doi.org/10.1016/j.asr.2020.04.021.
25. Bernhard, P., Deschamps, M. and Zaccour, G. (2023). Large satellite constellations and space debris: exploratory analysis of strategic management of the space commons. *European Journal of Operational Research*, 304(3), 1140-1157, https://doi.org/10.1016/j.ejor.2022.04.030.
26. Capurso, A., Marzioli, P. and Boscia, M. (2023). Questions of fault liability: A case study analysis of in-orbit collisions with debris. *Journal of Space Safety Engineering*, 10, 439-446, https://doi.org/10.1016/j.jsse.2023.08.001.
27. Chowdhury, D. D. (2022). The Conundrum of Space Debris and Its Sustainable Remediation by Polluter Pays Principle. *NUJS Journal of Regulatory Studies*, 7(3), 99-110.
28. Drechsler, W. and Kostakis, V (2014). Should Law Keep Pace With Technology? Law as Katechon. *Bulletin of Science, Technology & Society*, 34(5-6), 128-132, https://doi.org/10.1177/0270467615574330.
29. Hobe, S. (2010). The Impact of New Developments on International Space Law (New Actors, Commercialisation, Privatisation, Increase in the Number of "Space-faring Nations"). *Uniform Law Review*, 15(3-4), 869–881, https://doi.org/10.1093/ulr/15.3-4.869.

30. Hutchison, K. et al (2017). Managing the Opportunities and Risks Associated with Disruptive Technologies - space law in New Zealand. *Policy Quarterly*, 13(4), 28-35, https://doi.org/10.26686/pq.v13i4.4617.
31. Kessler, D. and Cour-Palais, B. (1978). Collision Frequency of Artificial Satellites: The Creation of a Debris Belt. *Journal of Geophysical Research*, 83(A6), 2637-2646, https://doi.org/10.1029/JA083iA06p02637.
32. Larsen, P. B. (2017). Small Satellite Legal Issues. *Journal of Air Law and Commerce*, 82(2), 275-310.
33. Larsen, P. B. (2018). Solving the Space Debris Crisis. *Journal of Air Law and Commerce*, 83(3), 475-520.
34. Martinez, P. (2022). The development and implementation of international UN guidelines for the long-term sustainability of outer space activities. *Advances in Space Research*, 72, 2597-2606, https://doi.org/10.1016/j.asr.2022.06.046.
35. Muelhaupt, T. J., Sorge, M. E., Morin, J. and Wilson, R. S. (2019). Space traffic management in the new space era. *The Journal of Space Safety Engineering*, 6, 80-87, https://doi.org/10.1016/j.jsse.2019.05.007.
36. Nishida, S., Kawamoto, S., Okawa, Y., Terui, F. and Kitamura, S. (2009). Space debris removal system using a small satellite. *Acta Astronautica*, 65, 95-102, https://doi.org/10.1016/j.actaastro.2009.01.041.
37. Sheer, A., Fatima, S., Farooqui, M. O. and Kasuri, M. R. (2023) A panacea to address the legal, administrative and economic aspects of space debris. *Advances in Space Research*, 72, 2616–2626, https://doi.org/10.1016/j.asr.2023.02.023.
38. Suwijak, C. and Li, S. (2021). Legal Challenges to the Construction and Operation of Small Satellite Constellations. *Journal of East Asia & International Law*, 14, 131-146, http://dx.doi.org/10.14330/jeail.2021.14.1.07.
39. Sweeting, M. N. (2018). Modern Small Satellites – Changing the Economics of Space. *Proceedings of the IEEE*, 106(3), 343-361, https://doi.org/10.1109/JPROC.2018.2806218.
40. Yang, K. and Wu, Y. (2022). Improving international governance of space debris in the era of large constellations of small satellites and China’s response. *Advances in Space Research*, 72, 2607-2615, https://doi.org/10.1016/j.asr.2022.06.061.

Court Practice

41. United Nations Reports of International Arbitral Awards. 16 April 1938 and 11 March 1941. *Trail smelter case (United States, Canada)*. Volume III pp. 1905-1982.

Other

Websites

42. ESA. *Objects detected in the vicinity of ClearSpace-1 debris removal mission target*. [online] (modified 22 August 2023). Available at: https://www.esa.int/Space_Safety/Objects_detected_in_the_vicinity_of_ClearSpace-1_debris_removal_mission_target#:~:text=On%2010%20August%202023%2C%20ESA's,spaceport%20in%20Kourou%2C%20French%20Guiana [accessed 21 December 2023].
43. ESA. *Space debris by the numbers*. [online] (modified 12 September 2023). Available at: https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers [accessed 17 October 2023].
44. GlobeNewswire. *Global On-Orbit Satellite Servicing Market Size To Worth USD 6.14 Billion By 2032 | CAGR of 10.7%*. [online] (modified 14 November 2023). Available at: https://www.globenewswire.com/news-release/2023/11/14/2780093/0/en/Global-On-Orbit-Satellite-Servicing-Market-Size-To-Worth-USD-6-14-Billion-By-2032-CAGR-of-10-7.html [accessed 15 December 2023].
45. News9live. *ESA funds study to tackle space debris by deploying swarm of satellites in low Earth orbit*. [online] (modified 09 October 2023). Available at: https://www.news9live.com/science/esa-funds-study-to-tackle-space-debris-by-deploying-swarm-of-satellites-in-low-earth-orbit-2313977 [accessed 15 December 2023].
46. Space.com. *SpaceX Starlink satellites had to make 25,000 collision-avoidance maneuvers in just 6 months — and it will only get worse*. [online] (modified 06 July 2023). Available at: https://www.space.com/starlink-satellite-conjunction-increase-threatens-space-sustainability [accessed 15 December 2023].

47. SpaceX. *Launches*. [online] (modified 08 December 2023). Available at: https://www.spacex.com/launches/ [accessed 20 December 2023].
48. SpaceNews. *FCC approves new orbital debris rule*. [online] (modified 29 September 2022). Available at: https://spacenews.com/fcc-approves-new-orbital-debris-rule/ [accessed 15 December 2023].
49. SpaceNews. *FCC issues warning in wake of Swarm's unauthorized launch*. [online] (modified 13 April 2018). Available at: https://spacenews.com/fcc-issues-warning-in-wake-of-swarms-unauthorized-launch/ [accessed 15 December 2023].
50. Spherical Insights. *Global Satellite Market*. [online] (modified June 2023). Available at: https://www.sphericalinsights.com/reports/small-satellite-market [accessed 15 December 2023].
51. The New York Times. *Dish Is First Company to Be Fined by F.C.C. Over Space Junk Rule*. [online] (modified 03 October 2023). Available at: https://www.nytimes.com/2023/10/03/business/dish-fcc-space-debris-fine.html [accessed 15 December 2023].
52. Warwick. *Satellite swarm to provide 'missing link' between space weather and space debris*. [online] (modified 05 October 2023). Available at: https://warwick.ac.uk/newsandevents/pressreleases/?newsItem=8a17841b8af5746a018affde8e054712 [accessed 15 December 2023].

Reports

53. Bryce Tech. 2022 Orbital Launches Year in Review (2023). Available at: https://brycetech.com/reports.
54. Bryce Tech. 2020 Orbital Launches Year in Review (2020). Available at: https://brycetech.com/reports.
55. Bryce Tech. Smallsats by the Numbers (2022). Available at: https://brycetech.com/reports.
56. Report of the Committee on the Peaceful Uses of Outer Space, COPUOS 66th session (2023). Symbol A/78/20. Available at: https://www.unoosa.org/oosa/oosadoc/data/documents/2023/a/a7820_0.html.
57. Report of the Committee on the Peaceful Uses of Outer Space, COPUOS 64th session (2021). Symbol A/AC.105/1240. Available at:

https://www.unoosa.org/oosa/oosadoc/data/documents/2021/aac.105/aac.1051240_0.html.

58. ESA's Annual Space Environment Report (2023). Reference GEN-DB-LOG-00288-OPS-SD. Available at: https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

Non-Regulatory Guidelines and Recommendations

59. IADC Space Debris Mitigation Guidelines (2021). IADC-02-01 Rev. 3.
60. IADC Statement on Large Constellations of Satellites in Low Earth Orbit (2021). IADC-15-03 Rev. 1.1

Conference Papers

61. Virgili, B. and Krag, H. (2015). Small Satellites and the Future Space Debris Environment. 30th ISTS - International Symposium on Space Technology and Science. Available at: https://www.researchgate.net/publication/281614713_Small_Satellites_and_the_Future_Space_Debris_Environment [Accessed 21 December 2023].

SUMMARY

Managing Space Debris in the Age of Small Satellites: Proposals for Regulatory Action

Marcus Fabian Brinck

This Master's Thesis provides an overview of the global problem of space debris, aggravated by the emerging use of small satellites by often private actors in space, and assesses potential solutions through regulatory means on an international level. For this purpose, selected international agreements and guidelines of various institutions which represent the current standing on space debris related rules are summarized and evaluated in order to identify aspects for improvement. Such rule sets include the international space treaties, in particular the Outer Space Treaty of 1967, as well as the various guidelines of the United Nations covering issues related to space debris mitigation. Moreover, also recent recommendations of non-regulatory international institutions, like the World Economic Forum and the European Space Agency are assessed to present a comprehensive coverage of the global approaches to manage space debris. Subsequently, various conceivable approaches to improve the international legal framework on space debris are considered, particularly questions as to whether a solution on the international level is necessary, what kind of international legal instruments are suitable and whether such a legal framework needs to specifically address new small satellite technologies in order to sufficiently tackle the space debris issue. Finally, several concrete proposals on how to improve the existing international legal framework on space debris by revising some of the current space debris mitigation rules and establishing a legal framework for active removal of space debris are made.

SANTRAUKA

Kosminių šiukšlių valdymas mažų palydovų amžiuje: pasiūlymai dėl reguliavimo veiksmų

Marcus Fabian Brinck

Šiame magistro darbe apžvelgiama pasaulinė kosmimių nuolaužų problema, kurią dar labiau paaštrina privačių subjektų vis dažniau pradedami naudoti mažieji palydovai, ir įvertinami galimi sprendimai, kuriuos galima išspręsti tarptautiniu lygmeniu taikant reguliavimo priemones. Šiuo tikslu apibendrinami ir įvertinami pasirinkti įvairių institucijų tarptautiniai susitarimai ir gairės, atspindintys dabartinę su kosmoso nuolaužomis susijusių taisyklių padėtį, siekiant nustatyti tobulintinus aspektus. Tokie taisyklių rinkiniai apima tarptautines kosminės erdvės sutartis, visų pirma 1967 m. Kosminės erdvės sutartį, taip pat įvairias Jungtinių Tautų Organizacijos gaires, apimančias su kosmoso nuolaužų mažinimu susijusius klausimus. Be to, įvertintos ir naujausios nereguliuojančių tarptautinių institucijų, pavyzdžiui, Pasaulio ekonomikos forumo ir Europos kosmoso agentūros, rekomendacijos, siekiant išsamiai aprėpti pasaulinius kosminių nuolaužų valdymo metodus. Tuomet nagrinėjami įvairūs galimi būdai, kaip patobulinti tarptautinę teisinę kosmoso nuolaužų reguliavimo sistemą. Visų pirma keliami klausimai, ar būtinas tarptautinio lygmens sprendimas, kokios tarptautinės teisinės priemonės yra tinkamos ir ar tokioje teisinėje sistemoje turi būti konkrečiai aptariamos naujos mažų palydovų technologijos, kad būtų galima tinkamai spręsti kosmoso nuolaužų problemą. Galiausiai pateikiami keli konkretūs pasiūlymai, kaip patobulinti esamą tarptautinę kosminių nuolaužų teisinio reguliavimo sistemą, peržiūrint kai kurias dabartines kosminių nuolaužų mažinimo taisykles ir sukuriant aktyvaus kosminių nuolaužų šalinimo teisinę sistemą.