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Planetary Engineering Ethics: Mechanisms, Issues, and Consequences of Terraforming

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Under consideration of scientists using engineered tools for scientific discovery, it may be a natural curiosity to question the physical realities of fabricating the biosphere conditions of habitable spaces beyond Earth's atmosphere and how we can study for and innovate new engineering systems to probe the scientific secrets of our universe through space exploration, settlement, and modification. Outer-Earth habitable spaces and the human condition require an understanding of the limits of ecological capabilities in largely unchartered habitats (such as the Martian habitat) for the regulation of life. Of particular concern are the questions from the engineer's perspective influencing the work accomplished and contributed to science: When engineering tools and spaces for the territorializing of planets other than Earth, what ethical appropriations are necessary to be considered? How do we analyze the ethics behind potential outer space habitability using real science? How are planetary modification engineers tested to maintain the "*health, safety, and welfare*" of humans and other possible life forms when engineering terraforming mechanisms? To address the ethical dimensions of terraforming, scientists such as Carl Sagan, M.J. Fogg, and NASA's Christopher McKay have researched and analyzed the extent to which terraforming is justified. Since the area of planetary engineering and terraforming is mainly approached from a theoretical and hypothetical perspective, much of the scientists' arguments are built on scientific research, hypotheses, and assessments of potential conditional attributes of terraforming other planets rather than on documented instances. While the creation of a habitable climate of a self-regulating anaerobic biosphere requires assessments of technical feasibility, reasonable objectives, and environmental effects, for the sake of humanity, we must, at the same time, consider planetary engineering ethics through fundamental aspects of ethical viewpoints. This research and analysis paper will address this extension of environmental ethics in the area of planetary engineering, specifically using the following three ethical viewpoints that inevitably shape our perceptions of the terraforming endeavors proposed to build our cosmological future appropriately: [1] **environmental ethics analysis**, [2] **moral theories analysis** (**including utilitarianism**, **Respect for Persons ethics** or "**RP ethics**," and **virtue ethics**), and [3] **risk analysis**. The three ethical viewpoints, explained in "Concepts and Cases: Engineering Ethics. 6th Edition," are used to elaborate justifications for or against terraforming beyond the mere theoretical explanations. To develop the justifications of the "*intrinsic value*" of terraforming, scientific evaluations, research, and experimentation in planetary engineering mechanisms, relevant issues addressed by proponents and opponents of terraforming, and potential consequences from the inherent risks involved in engineering implementations for space exploration, settlement, and modification are explored through each ethical lens and by using mainly Mars as the example planet of interest.

The ethical dimensions of terraforming toward human space settlement arise the questions of the morality behind environmental colonization and induced ecological change. When considering **environmental ethics analysis** ([1]) involving biosphere synthesis and ecosystem fabrication, both the effects of the implementation of planetary engineering mechanisms on macro-ecological structures and on the chemical structures and processes underlying macro-ecological modifications must be examined to fully assess the effects of terraforming on the environment. To elaborate on the possible environmental consequences of planetary engineering, the analysis of the environmental ethics below includes a diverse set of approaches in arguing for or against the sustainable development practices of terraforming through ***ecocentric consequentialism***, ***environmental anthropocentrism***, ***eco-centric extremism***, and ***preservationism***. The perspective *of* ***ecocentric consequentialism*** approaches environmental ethics analysis through a similar argument as the test of maximization of good from the utilitarian approach. In "The Ethics of Outer Space: A Consequentialist Perspective" by Seth D. Baum, Seth explains that "*the ecocentric consequentialist would say that it is permissible if space colonization results in a net increase in ecosystem flourishing*." While the "*net increase in ecosystem flourishing*," however, cannot be entirely proven, some scientists have proposed methodologies for ecosystem modification and subsequent flourishment. One significant methodology considers eco-chemical adaptation by making greenhouse gas factories for trapping solar radiation as induced global warming. This method would require the greenhouse gas factories to either be ferried to Mars in a lightweight and efficient way or made from Martian materials. The greenhouse machines would mimic the natural process of plant photosynthesis for plants to inhale carbon dioxide and emit oxygen. The sole purpose of engineering these greenhouse gas factories would be to pump out chlorofluorocarbons (CFCs), methane, and other greenhouse gases into the atmosphere. Bioengineering photosynthetic bacteria is another methodology in place of or in addition to the greenhouse machines. NASA has also researched a solar sail propulsion system whereby the use of large reflective mirrors harnesses the sun's radiation to propel spacecraft through space; the mirrors can possibly reflect the sun's radiation to heat the Martian surface. The large mylar mirrors are proposed to be roughly 200,000 tons and too large to be launched from Earth, which requires that the mirrors be made out of space material. These methodologies are considered questionable. The fact that an extremely large amount of funding would be required to enact research and development projects contributes to the ethical question of whether or not it is worth it to invest in such projects, especially if the "*net increase in ecosystem flourishing*" is not entirely guaranteed through conclusions made from previous trial and error.

The perspective of ***environmental anthropocentrism*** considers that space colonization is justifiable as an improvement unless it caused harm to animals, for example via back contamination. The environmental anthropocentric approach is akin to the requirement of adherence to a cradle-to-cradle environmental development cycle within one habitable incubation: to justify space colonization, the engineering systems and processes must be isolated from the Earth's habitat. From the perspective of environmental anthropocentrism, it is of significance to consider the question: To what extent can we expect, detect, and monitor changes to Earth's biosphere and its living organisms from space-colonizing systems and processes? ***Eco-centric extremism*** argues that the host biosphere of life has the right to evolve without outside interference: Incorporating similar attributes as RP ethics, this perspective sees the utmost importance in the moral imperative to preserve the individual decision-making and adaptive abilities of one biosphere without peripheral effects from the other biospheres. It may be considered exploitation of resources if rights are violated through means of planetary engineering. According to eco-centric extremism, biospheres should develop as separate incubations: Any effects that cause a change from one biosphere to another are considered interruptions and violations of the rights of the altered biosphere. Lastly, ***preservationism*** holds the most extremist viewpoint through the argument that space colonization is never morally permissible. An approach that Rachel Carlson may have approved of, preservationism requires pertinence to the conservation of Earth and its environmental resources first and foremost to the avail that any engineering methodologies to terraform another planet would be out of the question and indeed may be seen as blasphemous since terraforming is more of a science-fiction or pseudoscience rather than true science. Preservationism holds that our moral obligation to engineer sustainable development methods for Earth should be the highest esteemed ethical responsibility.

The **moral theories analysis** ([2]) includes ***utilitarianism*** *(using the* ***test of maximizing good consequences*** *and the* ***cost-benefit test)***, ***RP ethics***, and ***virtue ethics***. In the view of ***utilitarianism***, as held by Carl Sagan and Martyn Fogg, ethical permissibility for planetary engineering is conducted based on the justification that terraforming is a moral obligation for the sake of the maximization of the benefits for the future generations, as Earth will eventually be destroyed due to environmental consequences of our host planet and it would be irresponsible to ignore the astrobiological benefits to space colonization. The motivation for maximization of overall benefits through terraforming is reliant on the test of maximizing good consequences or the cost-benefit test: The former is imaginably experimental in the context of the rearrangement of another planet's environment through modifications incorporating energy balance, material composition, physicochemical parts and assemblages, and ecosystem processes for the sake of future habitability as we have evidence that these efforts will consequentially outweigh the inevitable dystopia of Earth while the latter argues for the necessity of the economic criteria of terraforming. The ***test of maximizing good consequences*** asks the question: Will terraforming result in more utility than any other alternative action available? Possible utilitarian interests may involve the mere escape from Earth, discovery and acquisition of resources unavailable to Earth, and enhancement of knowledge of extraterrestrial life forms. While there is significance in understanding that these benefits are potential benefits and not necessarily evidenced benefits, the utilitarian argument for terraforming could be favorable in the sense of moral responsibility when considering the extent to which aspiring and intelligible organizations such as NASA have engineers and scientists working on credible research and experimentation for planetary probing and engineering over the mere idealistic and cultural dichotomies underlying the concept of space colonization. Turning ignorant to the possibilities of terraforming, nevertheless, is reductionist and unfavorable to Sagan and Fogg. Yet, a practical ethical analyst may invariably question the support of terraforming through the economic feasibility of its application by using the ***cost-benefit test***. Investment in R&D of terraforming space technologies and planetary modification engineering necessitates new space programs. The federal budget deficit and debt contribute to NASA's inability to increase its own agency budget. The costs of new terraforming space programs may require extensive appropriations by government committees. We can, however, make some deductions based on real data on the "*space*" category toward government spending: The government spending (per capita) for the category of "*space*" is the lowest out of all spending categories at $52 per each American per year (pg. 73-74, Budget of the US

Government, FY 1991, "The Case For Space"). The weakness of the economic dominance of contribution to civilian space efforts, however, may change after the establishment of President Reagan's Strategic Defense Initiative (SDI) in the 1980s. "*Terraforming space*" (as space modification) would be an entirely new and separate category, which one could argue would receive the least amount of government funding, falling behind "*space*" (space exploration and settlement). The economic benefits of terraforming are aside from the documented estimates of benefits from space exploration technologies for areas including communications/data processing, transportation, industrial, medical, environmental, energy, and public safety, since a comprehensive analysis of terraforming's operational benefits requires new agenda, regulation, and scientific research and development for the establishment of a radical terraforming space program. Thus, in the case of terraforming, the cost-benefit test can only be theorized and not numerically applied with true and updated data.

In the view of ***RP ethics***, the potential for back-contamination is of great concern since it may be possible that the contaminants could travel as space debris from another planet to Earth. If back-contamination were to occur, humans would be defeated against their ability to exercise their right to life and preservation of physical integrity without susceptibility to bodily harm in the form of a bacterial infection or viral contamination, individual or widespread disease, or death. The free and equal moral agency of humans would be depleted if uncontrolled back-contamination were to occur; therefore in the hypothetical case that space travel of micro bacteria or viral entities were to occur from one planet to Earth, it would be presumed that humans did not choose to allow this travel to happen. Likewise, if we were to send astronauts to another planet, an ethical analyst could use RP ethics to ensure that the astronauts have complete transparency through informed consent and the free will to make individual decisions to travel through space and modify the new planet with an understanding of the hypothetical conditions involved in such an endeavor. This informed consent to which astronauts abide would include the possibility of back-contamination.

In the view of ***virtue ethics***, the enhancement of human capabilities through the application of human virtues must be observed to understand the "*intrinsic value*" of space colonization. Christopher McKay of NASA takes a conditional viewpoint that combines virtue ethics with the capabilities approach, seeing that terraforming is ethically permissible if we know that the alien planet does not harbor life already and that if it does, we should engineer the alien environment to help it thrive or even co-evolve and co-exist with the human species. Using McKay's justification, induced "*contamination*" of Mars (or other appropriately researched and ecologically viable planets) with Earth's bacteria, algae, or protozoa through our modification of their living conditions and evolutionary survivals could be the morally permissible beginning of our terraforming the lowest forms of life, whether or not we have found that there are already similar life forms on the planet of interest. The method of "*cross-seeding across colonies*" may be an experimental and incremental method to induce systematic change through small steps. Observation of ecosystem responses and employment of feedback mechanisms could help develop space life colonies. The idea that the scientist would be acting in the way that a virtuous person would act in the circumstance that enables the development of space life colonies for the potential co-evolution and co-existence on another planet through terraforming experimentations demonstrates the virtue of scientific courage. The effects of the conditional application of the virtue of scientific courage through terraforming experimentation despite unknown factors are the infrastructure for the capabilities approach: Our ability to live the life we have reason to value (which includes the highest state of coexistence with the potential of nature) may improve responsively to any positive moral habituation practiced by the virtue-strengthening actions involved in the scientific experimentations of terraforming.

If terraforming is inevitably a high-risk endeavor, how do we distinguish the engineering variables involved that would ensure operative fluidity and proper environmental fluency? How certain can safety protocols and space modification regulations be in the determination of appropriations for terraforming technologies and systems? To address these ethical questions, an engineer's responsibility to make assessments of and manage terraforming risks requires information on possible detrimental consequences of example terraforming technologies on the Earth's habitat and inhabitants through **risk analysis** ([3]). Possible detrimental consequences include an increase in space debris, celestial object collisions leading to unnatural galactic differentials, back-contamination, loss of valuable government funding from mission failures, space weather effects on Earth's technology infrastructures, atmospheric degradation, loss of Earth's nonrenewable resources, impairment of natural human tendencies and capabilities, and loss of life, personal injury or illness during space missions. Qualitative investigations and quantitative data collection and analysis through instrumentations alongside engineering mechanisms and scientific methodologies could provide valuable insight into contributing factors and detectable consequences inherent in terraforming risks. An engineer's responsibility toward the management of risk, with complexities respective to an engineering example to which the risks pertain, typically develops through the implementation of projects with the incorporation of standard design codes and regulations. With terraforming, however, risk acceptability and tolerability are seemingly low due to public perception of the innovative and largely untested attributes behind planetary engineering and the dynamically uncontrollable aspects of the space environment at large. A lack of established design codes and compliance requirements leaves the terraforming engineer void of regulatory accuracy and measurable expectations in projects; Engineering judgments for appropriate standards of care seem to be currently unapproachable. One example of a terraforming technology that would require extensive engineering risk assessment and management is asteroid mining. Using the capabilities approach, an engineer can predict how to manage risks associated with asteroid mining through the assessment of qualitative life attributes that would be affected by the potential adverse effects and hazard opportunities of asteroid mining. Proposed by Christopher McKay and Robert Zubrin, hurling large, icy asteroids containing ammonia could produce tons of greenhouse gases and enough water to cover 25% of the Martian surface, warming the Martian ecosystem and providing habitable conditions, if these asteroids were to collide with Mars. The inherent risks associated with the Martian bombardment by asteroids, however, involve the high release of energy equivalent to 70,000 one-megaton hydrogen bombs, which would take centuries to accomplish and may cause dangerous atmospheric reactions. The hypothesized temporal delay of human settlement of Mars for centuries, one risk involving the extreme contribution of time, makes asteroid mining and the general motivation for terraforming seem to be adversity-causing and capabilities-depriving objectives that are at the mercy of time (especially because mere settlement long precedes terraforming). The engineer may have to reason how prioritizing research, development, and implementation of asteroid mining and similar methodologies could be justified if human capabilities would not be enhanced for years to come while the potentially disastrous consequences of celestial objects modifications may increase space debris and make irreversible changes to energetic collisions and orbital mechanics.

Astrophysicists, engineers, mathematicians, and scientific experimenters alike have long sought to answer the largest questions about the nature of existence, while those bold adventurers, the astronauts, reach toward undiscovered edges with the help of engineers who design and build for potential survival beyond what humans have long evolved to endure here on Earth. The exploration and application of ethical approaches to planetary engineering are especially significant so that engineers can develop analytical methods for justifications for moral responsibilities of terraforming and the implementations of terraforming engineering methods in this area of scientific discovery that may reveal the most about our purpose and our highest potential to discover the unknown. Laymen, the general public, academic institutions, industry, and governmental organizations may also be presented with a more informative, unbiased, and multifaceted paradigm to reason the significance and implications of terraforming, influencing public policy, funding channels, our interactions with the natural world, and may enthusiastically encourage a paradigm shift to find solutions toward space exploration, settlement, and modification. Yet larger questions remain in the great unknown of terraforming. Ultimately, is it "*outside our nature*" or "*within our nature*" to involve the human act of space settlement and modification in environments widely unexplored?

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