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Exploring space: ethical dilemmas for catholicism

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This article explores the Catholic Church's perspective on space exploration and construction of human settlements beyond Earth, highlighting the significant moral dilemmas posed by these endeavors. While the Church generally supports space exploration, biotechnologies such as genome editing, assisted reproduction, and artificial wombs – technologies potentially essential for human survival and reproduction in space – clash with its moral principles. Non-therapeutic genetic modifications, regarded by the Church as an arbitrary redesign of human nature, are categorically prohibited. Similarly, assisted reproduction is considered morally unacceptable due to the destruction of embryos, the separation of the unitive and procreative aspects of human sexuality, and it fosters the selection of embryos and eugenics practices. Although the use of artificial wombs offers practical and safety benefits in space, it is also incompatible with the Church's teachings on the dignity of human life and procreation. These conflicts underscore the Church's challenge in reconciling humanity's aspirations for space exploration with its ethical and spiritual framework. If technologies that fundamentally alter human nature or reproduction are excluded, the prospect of human expansion into space may remain morally unattainable.

KEYWORDS

space biothics, Catholic Church, genome editing, assisted reproduction, artificial womb

1 Introduction

Does the Catholic religion consider space travel morally acceptable? And do the projects for space expansion and the construction of new settlements on other planets survive moral scrutiny? It seems that Catholics are not barred from adopting an open, favorable stance toward exploration and settlement of extraterrestrial territories. On several occasions, popes and representatives of the Catholic Church have expressed highly positive opinions about the efforts to send humans into space and to international space stations. As early as in his message to the Conference on the Peaceful Use of Outer Space (6 August 1968), Paul VI expressed the hope that space exploration would promote the unity of peoples, not be used as a tool of war and oppression, and benefit the less fortunate. The enormous progress in space technology "which the world has witnessed with admiration for some years now," Paul VI stated, "should be put to the service of peace and the common welfare of mankind," concerning the moral principles consistently proclaimed by the Church: "If this is done, space will advance in order and not in confusion and rivalry. (. . .) If this is done," Paul VI concluded, "it will benefit all people and not just the privileged few" (Paul VI, 1968a). At the beginning of the space era, however, papal messages were generally limited to prayers for the astronauts (Consolmagno, 2020). For instance, this was the tone of the message sent by Paul VI from the Vatican Observatory to the Apollo 11 crew on the day of their moon landing. A year later (15 April 1970), another prayerful message was addressed to the American

astronauts of Apollo 13 (Consolmagno, 2020). During the 1984 Conference organized by the Pontifical Academy of Sciences, entitled Impact of Space Exploration on Mankind, Pope John Paul II (1984) expressed hope, reiterating Paul VI's earlier sentiments, that the benefits of space travel and planetary exploration would not be reserved for a privileged few but shared among all. As Guy Consolmagno (2020) recalls, Pope Francis made a similar appeal in 2018 during a meeting hosted by the Vatican Observatory and financed by the United Nations Office of Outer Space Activities (UNOOSA), emphasizing the need for and importance of facing the moral challenges of our time.

At the subsequent Vienna meeting (UNISPACE+50), Guy Consolmagno, head of the Vatican delegation, presented the official position of the Catholic Church, once again underscoring the importance of using the wealth of data and services deriving from space exploration for the benefit of all. On other occasions, Consolmagno (2019), director of the Vatican Observatory, stated that humanity should not view space exploration solely as an opportunity for economic development, as it can also be a chance to contemplate creation. Furthermore, Consolmagno asserted, we must remember that, for the Catholic religion, we are stewards of creation, which includes extraterrestrial space. According to Consolmagno (2020), the encyclical Laudato Si', published by Pope Francis in 2015, which addresses caring for the Earth as a common home and highlights the interconnectedness of environmental, social, and economic issues, has broader significance. Its message, he suggested, extends not only to our planet but also to outer space. Finally, he claimed that, through the exploration of extraterrestrial worlds, we could come much closer to understanding the mystery of life and, ultimately, discovering its meaning: "God," he declared, "created man as an intelligent thinking creature. He created a universe of endless wonder and intricacy. We are meant to explore and to be amazed" (Gooch, 2023). From this perspective, not only space exploration (and the construction of new settlements) but also the observation of the heavens are consistent with the Church's function and religious duties, as science might prove God's existence or be the path to a personal encounter with the divine. (Through the knowledge of the heavens, we might ultimately come face to face with God.)

The Catholic Church, however, does not exclude the possibility of other encounters. In 2014, Pope Benedict (2011), who had previously affirmed that space exploration could be guided by noble ideals and promote the common good (Talk of His Holiness Benedict XVI with the Astronauts in Orbit, 21 May2011[1]), stated that venturing into space might also allow humanity to encounter other forms of life. He added that even a Martian would have the right to receive the Catholic faith and be baptized: "Imagine if a Martian showed up, all big ears and big nose like in a child's drawing, and asked to be baptized" (Consolmagno and Mueller, 2014). This position is also shared by Consolmagno and Mueller, who have stated that they would have no difficulty in baptizing an extraterrestrial since any entity, no matter how strange it may appear to us, has a soul[2]: "Any entity, no matter how many tentacles it has, has a soul (Jha, 2010)." Years earlier, Father Gabriel Funes, former director of the Vatican Observatory, also failed to rule out the existence of extraterrestrial life in the universe, asserting, "As there is a multiplicity of creatures on Earth, there can be other beings, even intelligent ones, created by God. This is not in contrast with our faith because we cannot put limits on God's creative freedom" (Popham, 2008).[3]

From the outline we have presented, it seems that space, its exploration, and even settlement of other planets are not necessarily incompatible with the Catholic religion (Mazur and McFarland Taylor, 2023). However, we intend to demonstrate that space travel could challenge Catholic doctrine significantly and potentially conflict with its moral principles. In our view, the main issue is unrelated to the possibility of encountering 'extraterrestrial' life (Wilkinson, 2013; Peters et al., 2018). It has been suggested that meeting extraterrestrial beings could challenge the theoretical framework of the Catholic religion, as it might question the idea that humans (and the Earth) lie at the center of the divine plan, created in the image and likeness of God and therefore the sole recipients of the plan of salvation (Davison, 2023; Summers, 2024; Green, 2015). An encounter with other forms of intelligent life could raise significant theological questions, such as whether these creatures also possess souls, share in divine grace, or require redemption similar to that reserved for humans (Green, 2023). Furthermore, they might have a religious understanding based on a different revelation or incarnation (Gunderson and Traphagan, 2024).

In our opinion, however, the issue is not so much the possibility of encountering extraterrestrial individuals but rather the fact that space exploration and the construction of new settlements on the Moon or other planets (e.g., Mars) could require, or at least promote, extensive use of biotechnologies that the Catholic Church does not deem morally acceptable. First, we must consider that space exploration will likely necessitate genetic modification interventions that alter human characteristics, as humans are not biologically equipped to survive on other planets. It is reasonable to imagine that astronauts participating in settlement missions and willing to spend extended periods in space might have to undergo genome editing interventions before departing for other planets (Szocik et al., 2020). The problem is that these interventions would not be therapeutic but rather forms of 'enhancement' or would at least result in non-therapeutic changes to human characteristics, as humans could survive without modification. (Naturally, genetic modification might be essential for survival in space or on another planet, but humans would not require genetic

1 Talk of His Holiness Benedict XVI with the Astronauts in Orbit–via satellite connection with the Crew of the International Space Station (ISS), Foconi Hall, 21 May 2011: "Space exploration is a fascinating scientific adventure. It is also an adventure of the human spirit, a powerful stimulus to reflect on the origins and the destiny of the universe and humanity".

2 It seems that even Padre Pio spoke about the possibility of the existence of extraterrestrials. And John Paul II said: "They are children of God as we are" (Thigpen, 2022).

3 Beltramini (2019) notes that Pope Francis recently referred to "beings of the universe" in the same speech in which he reaffirmed the Catholic Church's positive views on the Big Bang (p. 7).

modification if they stayed on Earth. Moreover, when we talk about therapeutic intervention, we are referring to an intervention that allows the subject to regain a condition of normality that was lost or never had; here, the intervention merely aims to alter human characteristics.) The point is that, for the Catholic Church, enhancement interventions (regardless of where they are carried out: on Earth or in space) are never morally acceptable because (a) we do not have the right to play God and cannot claim the right to redesign human nature as we see fit (or according to our needs and preferences), and (b) there are natural limits we must respect, which prevent us from enhancing ourselves – even if this means forgoing the realization of essential objectives.[4]

The Catholic Church might consider space exploration (and, in this context, the construction of new and increasingly significant settlements) morally acceptable only if it does not require alterations to human nature that fundamentally change its inherent characteristics. In the discussion about space travel, the idea of genetically modifying astronauts arises from the understanding that environmental conditions in space are profoundly different from those on Earth and unsuitable for human survival (Szocik, 2023a; Kendal, 2024b). Rather than altering human nature, an alternative approach could involve adapting the surrounding environment. While terraforming projects on other planets may seem ambitious and technically challenging, there is no doubt that they could ensure human survival in space without necessitating genetic modifications (Balistreri and Umbrello, 2023; Milligan, 2015). The Catholic Church teaches that humans do not have the right to do whatever they wish with nature, as they have the duty to care for it responsibly, using it to ensure its exploitation is available to future generations (Francis, 2015). However, the terraforming of other planets could be morally justified as an example of responsible behavior toward nature in that it may increase its presence in otherwise uninhabitable environments. That is, these interventions would enrich, rather than destroy, living and abiotic nature.[5]

Nevertheless, even if space exploration or settlement could proceed without the need to genetically modify astronauts and the humans involved, building new settlements would still require technologies that the Catholic Church deems unacceptable. For instance, in these new settlements, reproduction might only be possible through assisted reproduction or the importation of embryos from Earth, as fertilization of the egg by sperm might be challenging in space (Mishra and Luderer, 2019; Balistreri, 2023).

Indeed, mammalian fertilization events have yet to be recorded in space (Szocik et al., 2018; Chaplia et al., 2024; Proshchina et al., 2021). The situation could change in the future, but what is known suggests that it could be challenging, if not impossible, to achieve human embryo fertilization. Even if circumstances were to change and fertilization became easier, assisted reproduction might still be preferred over natural conception due to the risk that radiation-induced genetic modifications in gametes could potentially jeopardize the health of the offspring (Balistreri and Umbrello, 2022). Assisted reproduction offers the advantage of screening human embryos and gametes to exclude those with defects or traits less compatible with a good quality of life for the offspring, allowing for the best selection.

On Earth, selecting human embryos may be morally controversial. Still, in space, it becomes a necessary choice so as to enhance chances of survival and ensure the health of offspring in an extremely hostile environment. Moreover, performing germline genome editing on embryos – which may be essential to ensure the survival of humans in space – would be much easier if the embryo is produced *in vitro* rather than within a woman's body. The intervention could occur immediately after fertilization when the embryo consists of only one cell (zygote), or in the subsequent developmental stage. Finally, if radiation irreversibly damages the gametes, IVF would become the only viable option for humans to have offspring. In this scenario, human embryos would be imported from Earth for reproduction. The embryos could be screened and then transferred to individuals at their destination. While the Catholic Church is unlikely to object to human reproduction in space, it considers IVF morally unacceptable because a) it involves the destruction of human embryos, b) it separates the generative act from the unitive one, and c) it fosters the selection of embryos and eugenics practices.

The Catholic Church might hold even stronger moral reservations about the artificial womb (ectogenesis). Whether fertilization occurs naturally or through assisted reproduction, the development of the human embryo currently still relies on pregnancy. However, in space, pregnancy could pose significant risks for women participating in missions. Moreover, it might limit or hinder their activities, thereby reducing the operational capacity of a crew and, in some cases, potentially threatening their survival (Kendall, 2024a). Therefore, in space mission an artificial womb might be considered the ideal solution – not only for the child being born (who could be monitored throughout its development and grow in an environment shielded from space radiation) but also for the women involved. Nevertheless, according to the Catholic Church, the artificial womb is morally objectionable for the same reasons for which assisted reproduction is criticized – namely, because it does not respect the human embryo, the dignity of procreation, or the conjugal act, and it entails the instrumentalization of life.

4 The Catholic Church considers genome editing acceptable only for therapeutic purposes, rejecting enhancement interventions as arbitrary redesigns of human nature. Furthermore, even the perceived benefits of space travel do not morally justify non-therapeutic genome editing. Allowing such modifications for ambitious projects like space exploration could pave the way for similar ones in other contexts, both in space and on Earth, whenever deemed necessary so as to achieve significant goals.

5 However, the situation could be even more complex, as the process of terraforming might irreversibly destroy non-human and potentially unknown forms of life, which are nevertheless part of nature (Persson, 2012). From a religious perspective, such intervention on nature could appear ethically inappropriate. Regardless of the increase in nature that humans might produce through terraforming, it would likely result in the permanent destruction of original life forms (species) or abiotic nature. The issue would deserve further exploration, but here our focus is on engaging with the simpler scenario where the terraforming of other planets is deemed morally acceptable. I thank Reviewer 1 for drawing my attention to this matter.

The second section delves into the ethical dilemmas of human enhancement, focusing on the Church's firm opposition to genetic modifications that fundamentally alter human nature. The third section explores the issue of assisted reproduction, emphasizing its moral incompatibility with Catholic doctrine due to the destruction of human embryos and the separation of procreation from the unitive act. Finally, the fourth section examines the concept of artificial wombs, underscoring their conflict with the Church's teachings on the dignity of human life and the sanctity of natural reproduction. Finally, we will conclude that the Catholic Church faces the challenge of reconciling technological advancements and humanity's ambitions in space with its ethical and spiritual principles (and theology). If morally acceptable space exploration and settlements exclude biotechnologies that fundamentally alter human nature and natural reproduction, space may remain an unattainable frontier for humanity.

2 Space travel and genome editing interventions

The exploration and settlement of space raise complex moral questions. One of the main ones concerns the balance between the significant costs associated with space projects and the needs of the current population on Earth. This sparks an ethical debate about how limited natural resources should be allocated between space research and societal needs, as well as the benefits that present and future generations can derive from space exploration. Although moral reflection in recent decades has increasingly focused on our responsibility toward future generations, the issue of the possible extinction of the human species remains underexplored (Torres, 2024). However, today, the problem is no longer merely the potential worsening of living conditions; an even more severe threat looms: the existential risk to the human species (MacAskill, 2022). Humanity could face annihilation from natural events such as an asteroid impact or a lethal pandemic or from reckless, irresponsible policies toward the future (Bostrom and Cirkovic, 2008). If we have a moral duty to ensure the survival of the human species, then we must become a species capable of surviving in space and on other planets. Space settlement would, in fact, not only provide an escape route in case of deterioration in the Earth's conditions (thus offering a "planet B") but also allow us to extend the presence of humanity beyond our natural boundaries.

Some argue that colonizing other planets ultimately comes down to two main strategies: altering humans so they may thrive in extraterrestrial environments or transforming those environments. Hence, they support human life (Garasic, 2024). In reality, these approaches are not mutually exclusive and might need to work together to establish sustainable settlements and create flourishing human communities in space. In recent years, the idea of using new technologies not only to prevent major diseases but also to enhance our capabilities has been central to bioethical reflection (Buchanan, 2011). Particular focus is laid on the possibility of intervening in the genetic makeup to improve not only physical but also mental traits, such as rationality (Harris, 2010; Savulescu et al., 2011). More recently, attention has also turned to moral enhancement, the possibility and morality of interventions aiming to improve individuals' ethical and moral dispositions (Harris, 2016). The debate on human enhancement is deeply polarized. On one side are those who defend the morality of the human enhancement project, some of whom argue that such interventions are even a moral obligation (Sorgner, 2022; Savulescu et al., 2011; Harris, 2010), believing that, if there are technical possibilities to improve the human condition, it is ethically right to exploit these so as to correct human nature. On the other side are those who argue that the use of biotechnologies such as genome editing may be morally acceptable for therapeutic purposes (and thus to restore or produce a natural condition) but never for enhancement ones. From this perspective, we can intervene to cure and prevent significant diseases. However, we should not attempt to redesign human nature, as this must be respected in its current dimension and form (Sandel, 2007; Habermas, 2016; Fukuyama, 2003; Hauskeller, 2013).

The Catholic Church is among those who adopt a critical stance toward any form of human enhancement (Ramsey, 1970; Sgreccia, 2012). According to the Catholic Church, any human enhancement intervention is morally objectionable both from a deontological perspective and in terms of its consequences. First and foremost, the Church believes that the desire to redesign human nature signifies arrogance and an intent to replace God: "It should also be noted that the attempt to create a new type of human reflects an ideological dimension, wherein humanity presumes to take the place of the Creator" (Congregation for the Doctrine of the Faith, 2008). Furthermore, attempting to redesign the characteristics of the human species shows a lack of respect not only for the Creator but also for human nature itself and the dignity thereof. Since the human body is considered a divine gift, humans should not presume the right to manipulate it or arbitrarily alter its distinctive characteristics. In cases of illness, they may intervene to restore a compromised condition, but they should not go beyond this and arbitrarily surpass their natural boundaries (Shannon, 2008; Cole-Turner, 2008). Thus, any enhancement project represents an unacceptable transgression of human limits and cannot even be regarded as a true enhancement, as human beings are created in the image and likeness of God and are, therefore, already "perfect". Finitude is part of our humanity, and erasing one aspect of it would also erase the other (McKenny, 2011). In other words, since the body can be considered the temple of the Holy Spirit, any intervention that modifies it diminishes its intrinsic value and distorts the divine image present in every individual (Pinsent and Biggins, 2019; Cherry, 2017). Such modifications risk undermining the sacredness and dignity that the human body inherently possesses: "Some have imagined the possibility of using genetic engineering techniques to carry out manipulations with alleged goals of improving and enhancing the genetic makeup. Some of these proposals manifest a kind of dissatisfaction toward or even rejection of the value of the human being as a finite creature and person" (Congregation for the Doctrine of the Faith, 2008).

Finally, human enhancement interventions do not respect intrinsic human dignity, as they treat human beings as objects that can be manipulated at will (Walter, 2008). For the Catholic Church, it is objects that we have the right to modify as we please; the value of human beings, however, should always be respected, regardless of their characteristics and irrespective of whether they conform to our preferences and projects. Such interventions that treat the human being as an object are intrinsically immoral because they imply and promote "the domination of man over man" (Congregation for the Doctrine of the Faith, 2008).

However, according to the Catholic Church, the potential consequences of human enhancement interventions must also be considered. Such interventions could pave the way for severe forms of discrimination. First, this might arise against individuals who are not enhanced, as enhancement procedures could be costly, limiting access to such benefits – whether physical or mental – to only the more privileged. This could lead to heightened inequality and discrimination (Ramsey, 1970). Moreover, enhancements such as extreme longevity or enhanced intelligence risk being mistaken for true transcendence, which is seen as a divine gift rather than a human achievement: "After all, one cannot easily engage in humble joint attention with the God of love if the entire focus of one's life is on HBEs with the aim of turning a few human beings into biotechnological gods" (Pinsent and Biggins, 2019). Then, also a limited enhancement program confined to space could still have serious consequences for humanity and potentially endanger the survival of the human species (Ventura and Balistreri, 2024). Earth-based humans might struggle to recognize genetically enhanced space inhabitants as humans, and those enhanced individuals might perceive themselves as posthuman species. Commercial relationships may be possible, but species with differing levels of intelligence and technology might perceive each other as threats. Over time, peaceful interplanetary relations based on solidarity and mutual respect might erode, leading to an escalating conflict marked by distrust and suspicion. To understand this dynamic, we may need to look back "to the long era in which *Homo sapiens* spread out of Africa and encountered, and probably drove to extinction, its close but somewhat less capable relatives, *Homo erectus* and *Homo neanderthalensis*" (Deudney, 2020: 342). Should war eventually break out, the genetically enhanced human species could prevail, potentially leading to the progressive extinction of unenhanced Earth-based humans, fostering processes of "ethnic replacement" or simply propelling humanity toward irreversible biological and genetic transformation (Ventura and Balistreri, 2024; Ćirković, 2022; Torres, 2018; Kovic, 2021; Milligan, 2023).[6]

Even if genetic modifications could be confined to space alone (and, in this scenario, be deemed more therapeutic interventions than enhancement) and had no short- or long-term consequences for our survival and future generations, there would still be a fundamental issue from the Catholic Church's perspective. The Church maintains that morally acceptable genetic modifications are those performed on the somatic line (adult individuals). Genetic modifications on the germline (embryos or gametes), on the other hand, are always morally condemned. At least for now, such genetic modifications inevitably involve assisted reproduction, which the Catholic Church considers morally unacceptable or unjustifiable.

The moral evaluation of *germ line cell therapy* is different. Whatever genetic modifications are affected on the germ cells of a person will be transmitted to any potential offspring. Because the risks connected to any genetic manipulation are considerable and as yet not fully controllable, *in the present state of research, it is not morally permissible to act in a way that may cause possible harm to the resulting progeny.* In the hypothesis of gene therapy on the embryo, it needs to be added that this only takes place in the context of *in vitro* fertilization and thus runs up against all the ethical objections to such procedures. For these reasons, therefore, it must be stated that, in its current state, germ line cell therapy in all its forms is morally illicit. (Congregation for the Doctrine of the Faith, 2008).[7]

Moreover, germline interventions would alter not only the genetic makeup but also the identity of the unborn, as the human body is not independent from the soul (Walter, 2001; Balistreri, 2024). Even without resorting to genetic modifications, prolonged stays in space or on another planet would gradually alter the physical and physiological characteristics of individuals living in an extraterrestrial environment. Over generations, these changes could lead to the emergence of a distinctly new species (a new human one!) shaped by the unique environmental pressures and conditions of these habitats (Deudney, 2020; Garasic, 2021; Braddock and Sharpe, 2022).

3 Space travel and assisted reproduction

However, even if space exploration or settlement could occur without the need to genetically modify astronauts, building new settlements would still require the use of technologies that the Catholic Church does not consider acceptable. We start from the fact that extraterrestrial environments exhibit extreme conditions (cosmic radiation, temperatures, microgravity) that appear incompatible with human survival. Currently, we lack technologies (such as spacesuits or systems capable of shielding a base camp built on another planet) that can adequately protect humans who might, in the future, undertake the expansion of humanity to other planets. As of now, there are two options for the feasibility of extended space missions beyond the Earth's lower orbit: the genetic modification of astronauts to make them better suited to space environmental conditions, or the radical transformation of the extraterrestrial environment through terraforming processes. So far, we have considered the possibility of space settlement occurring through technologies that allow the radical redesign of human nature. However, the other option – making profound interventions in nature – can also be considered. In the case of terraforming projects, the first issue to arise concerns the type of moral responsibility we have toward ecosystems and, possibly, other forms of life (Garasic and Di Paola, 2024; Milligan, 2015). Although positions in environmental ethics may attempt to include within the scope of morality not only non-

6 What we mean, therefore, is that, even if genetic modifications for astronauts to survive in space were classified as therapeutic rather than enhancement ones, this would not address the ethical concerns raised by Catholic doctrine. Any such genetic modification program would set in motion a transformation of the human species, potentially leading to a profound alteration of divine creation.

7 According to some scholars, however, this would not represent a principled opposition to interventions on the germline. In other words, if it were possible to perform genetic modifications on embryos or fetuses *in vivo*, or to genetically modify a person's gametes, these would no longer be considered illicit as they would be therapeutic (Shannon, 2008; Cole-Turner, 2008).

human animals but also plant organisms and superorganism entities such as species, ecosystems, and the planet itself (Rolston, 1988; Callicott, 1989; Leopold, 2013), it is debatable whether full moral relevance can be attributed to entities that lack consciousness (Balistreri and Umbrello, 2023; Persson, 2012; Persson, 2017). Damaging a plant or an ecosystem may be morally wrong only due to the consequences such actions bring to our interests and the wellbeing of animals.

Moreover, what we do to nature can diminish the world's inherent "aesthetic" value, preventing future generations, for example, from enjoying the beauty of stunning landscapes. Nevertheless, destroying a plant or interfering with the environment does not seem inherently wrong, as interventions on nature can increase human wellbeing and potentially benefit other sentient beings involved. Additionally, terraforming interventions can improve the intrinsic value of nature itself. After all, terraforming projects would increase the presence of nature (and thus plant or living organisms) even in extraterrestrial environments that currently appear to be devoid of life forms (Milligan, 2023; Milligan, 2015). Then, an urbanized landscape (with, for example, skylines, artificial lights, architectural installations, and soundscapes) could be just as beautiful and fascinating as a natural one (Weinersmith and Weinersmith, 2023). Furthermore, intervening on one planet or a very limited number of planets and asteroids would not diminish the 'natural' aesthetic value present in our solar system and, more broadly, the universe.

It is unlikely that terraforming projects alone could address the challenges posed by reduced or absent gravitational force. Instead, innovative housing solutions might mitigate or counteract these effects, creating more favorable living conditions on other planets without the need for genetic modification of human beings. Additionally, this approach could also overcome current issues related to sexual reproduction. At present, it is unclear whether humans can engage in sexual intercourse in space: under microgravity conditions, achieving or maintaining an erection might be either impossible or significantly more challenging (Cullen et al., 2023). Furthermore, due to the combined effects of microgravity and radiation, mammals might be unable to produce embryos capable of developing into viable individuals in space (Dubé et al., 2023; Proshchina et al., 2021; Watkins, 2020). For instance, recent studies have shown that the motility of human sperm thawed aboard the International Space Station was significantly lower compared to the control samples on Earth (Turner, 2023; Chaplia et al., 2024). Moreover, attempts to produce mammalian embryos (either by encouraging mating or using imported gametes) in space have been unsuccessful[8] (Jain et al., 2023). Similarly, efforts to complete the development of embryos created via assisted fertilization on Earth, cryopreserved, and then transported into space have also failed (Proshchina et al., 2021). Only recently has significant progress been achieved in the development of two-cell rat embryos transported to space (Wakayama et al., 2022; Yoshida et al., 2021). While this result implies that human reproduction beyond Earth might be possible, we are still far from being able to facilitate the birth of mammals in space (Watkins, 2020).

While terraforming interventions, combined with housing solutions designed to mitigate or counteract the effects of gravitational force, could make other planets safer and more habitable for humans, reproduction in such environments might still carry significant risks. In space, exposure to cosmic radiation could compromise the genetic integrity of gametes or result in genetic modifications that are incompatible with viable births – or which, even if they are compatible, potentially harm the offspring's health. We know that mammalian gametes might not undergo significant genetic alterations in space and can be successfully used in reproductive procedures on Earth, producing viable offspring even after a period spent in space (Proshchina et al., 2021). However, experiments with mammalian gametes in space have so far only been conducted aboard the International Space Station or on satellites positioned in the Earth's lower orbit (Jain et al., 2023). In deep space, cosmic radiation could have far more important detrimental effects on astronauts' gametes. The terraforming projects have the potential to shield human space communities from radiation, but it could take hundreds of years before such protection can be ensured through permanent environmental changes (Milligan, 2015). Even if new planetary settlements were adequately shielded, their inhabitants might still face increased radiation risks due to potential shield system failures or accidental exposures during outdoor activities beyond protected habitats, or during travel to and from Earth (or other planets).

Therefore, in space missions, assisted reproduction might be necessary not only to address fertilization issues but also to minimize the risk of transmitting genetic anomalies to offspring (Alon et al., 2024). Currently, transferring *in vitro* fertilization practices to space presents significant challenges, and further research is needed to understand its impact on the reproductive process, particularly on embryo development (Chaplia et al., 2024). However, things may change in the next future. The Catholic Church does not hold a principled opposition to human reproduction in space. However, it does fundamentally oppose any form of assisted reproduction. According to the Catholic Church, the use of assisted reproductive technologies is morally objectionable because: 1. It entails the destruction of human embryos (Congregation for the Doctrine of the Faith, 1987; Congregation for the Doctrine of the Faith, 2008); 2. It separates the reproductive moment from the unitive one (Pio, 1956; Paul VI, 1968b; Catechism of the Catholic Church, 1992; Congregation for the Doctrine of the Faith, 1987); 3. It reduces the offspring to an object, as it allows the selection of embryos based on the characteristics we consider better.

Assisted reproduction often leads to the destruction of embryos, mainly because these procedures create surplus embryos that go unused. This can happen when individuals successfully become parents on their first attempt or decide to discontinue treatment after initial failures. Moreover, life circumstances such as the death or separation of individuals may further prevent the use of cryopreserved embryos, leaving them abandoned indefinitely. While, in principle, these embryos could be adopted, the Catholic Church strongly opposes the adoption of embryos created *in vitro* (Brakman and Weaver, 2007).

Even in cases where surplus embryos are not produced, assisted reproductive procedures still inevitably involve experimentation and, consequently, the destruction of human embryos. Such techniques can only be refined through research involving the fertilization and subsequent development of numerous embryos, which are ultimately not used for reproductive purposes and

8 Several studies have shown that microgravity and spaceflight do not harm fertilization or embryo development in fish, amphibians, sea urchins, fruit flies and birds (Proshchina et al., 2021; Chaplia et al., 2024).

destroyed. The Catholic Church further deems assisted reproductive technologies morally unacceptable because they separate the unitive and reproductive aspects, which should never be divorced from each other. From this perspective, not only assisted reproduction, but also contraception is immoral. Contraception prevents the sexual act from achieving its reproductive purpose, while assisted reproduction enables human reproduction without the unitive aspect. Additionally, in assisted reproduction, sperm is typically collected through masturbation, and therefore, outside the context of a sexual act. At the same time, the fertilization of the egg does not occur as a result of an unitive act but rather through the intervention of third parties outside of the couple desiring a child.

Lastly, the Catholic Church argues that assisted reproduction fosters a eugenic mindset by enabling the selection of embryos based on desired or deemed superior characteristics (Rodger and Blackshaw, 2024). Such practices may also lead to stigma and discrimination against individuals who lack socially preferred traits or qualities, contradicting the fundamental principle of equality among all human beings (Congregation for the Doctrine of the Faith, 2008). Violating this principle of justice could have serious societal consequences, undermining peaceful coexistence and mutual respect among individuals.

4 The artificial womb and space travel

Space might ultimately be the ideal environment for promoting the use of artificial wombs. In space, even assuming that women could carry a pregnancy to term, artificial wombs may provide a far safer reproductive solution in comparison with natural reproduction – not only for the child to be born but also for the women themselves (Kendal, 2022). In a microgravity environment or under reduced gravity, the human body faces numerous challenges, such as loss of bone and muscle mass and circulatory system alterations, which could make both pregnancy over several months and childbirth itself particularly risky. Moreover, in space, a pregnancy could jeopardize not only the woman involved but also the crew engaged in the mission. A pregnant woman might become less available for physically demanding or otherwise strenuous activities, and, in the final stages of pregnancy, require specialized medical assistance, which may be only partially provided from Earth via technologies such as telemedicine (Maron, 2024). This situation could reduce the operational flexibility of the crew or community and, in the most challenging conditions, increase risks for all mission members. Finally, even if we had the technology to construct housing solutions capable of replicating Earth's gravity, while also providing adequate protection from radiation, and the reduced capacity of pregnant women were no longer an issue, artificial wombs could still offer women the possibility of having a child – potentially genetically modified or conceived through assisted reproduction – without the need to undergo invasive procedures, such as hormonal treatments or prenatal testing.

Artificial wombs can be used both for ectogestation and ectogenesis. The Catholic Church would probably have no difficulty in admitting the partial use of artificial wombs – namely, to save the life of a prematurely conceived embryo or fetus through sexual conception – since the human embryo is or must be treated as a person from the moment of conception. Since the human embryo is deserving of the dignity owed to a human person, it logically follows that the embryo would be equally worthy of life support and "rescue" from potentially fatal conditions, just as any person would be (Gross, 2024). Procedures involving intervention on embryos must meet only these conditions: they must respect the life and integrity of the embryo and not pose disproportionate risks (Congregation for the Doctrine of the Faith, 1987; Gross, 2024). From this perspective, ectogestation would simply be an advanced version of neonatal intensive care technologies, like incubators, already widely used in hospitals or birthing centers in Western countries. Ontologically, using an artificial womb would not change the embryo's condition; even in a biobag, the embryo would still have the same physiological needs, such as oxygenation, circulation, thermoregulation, and metabolism, as before (Partridge et al., 2017).

For the Catholic Church, the moral issue lies in using artificial wombs for reproductive purposes to replace not only a phase of pregnancy but the entire process of gestation and birth. Firstly, the use of artificial wombs (from conception to birth) would necessitate assisted reproduction, which, as discussed in the previous section, the Catholic Church considers an intrinsically immoral technology. This is because it involves the destruction of human embryos and separates the reproductive moment from the unitive one. From this point of view, the artificial womb would further cement the separation of the "reproductive" moment from the unitive one by rendering the woman's body redundant (or even, prospectively, a threat to the child to be born). However, the issue is not merely the separation of the reproductive and unitive moments but also the destruction of human embryos. Assisted reproduction technologies are generally associated with embryo selection procedures before transfer. Therefore, the use of artificial wombs would inevitably involve the destruction of human embryos that exhibit genetic anomalies or possess inferior genetic qualities in comparison with the available embryos.

According to the Catholic Church, such a practice would not only result in the destruction of embryos. Still, it could also transform human birth into an industrial activity, reducing those born to mere objects that can be programmed at will – and therefore discarded if they do not meet parental preferences. That is, this would be incompatible with respect for the principle of equality among persons. As Gilbert Meilaender (2019) argues, it assumes that the act of conceiving someone grants individuals the authority and the right to judge whether that person is worthy of existence, rather than fostering a sincere attitude of gratitude for the gift of their existence (Rodger and Blackshaw, 2024: 89).

Moreover, the idea that the Catholic Church could morally approve the use of an artificial womb as a means to bring into the world – and thus save – surplus human embryos appears not only controversial but also unconvincing in a space setting. David Reiber (2010) argued that, in this context, the artificial womb would have a limited ethically acceptable use – namely, initiating the development of those embryos created during assisted reproduction but then frozen and left unused. However, the Catholic Church not only forbids the adoption of human embryos but also asserts that the artificial womb, much like fertilization between human and animal gametes or the gestation of human embryos in animal wombs, violates human dignity (Rodger and Blackshaw, 2024: 89-90). Additionally, it breaches the right of every person to be conceived and born within the context of marriage (Gross, 2024). Even though the Catholic Church nowhere states that the adoption of human embryos is intrinsically illicit (Rodger and Blackshaw, 2024), it remains closely tied to assisted reproduction (and could, therefore, encourage individuals to resort to assisted fertilization techniques). Indeed, the possibility of

adopting human embryos could make IVF morally more acceptable or reduce the ethical concerns of those who turn to assisted reproduction techniques. According to Gross, for the adoption of human embryos to become morally acceptable to the Catholic Church, a profound cultural shift would be necessary, such as explicitly banning assisted reproduction or perceiving its intrinsic immorality. Otherwise, while it is true that the artificial womb could save human lives, it "also has the potential to diminish further how our culture views the sanctity of human life, the importance of marriage, and the value of motherhood through human pregnancy" (Gross, 2024).

Finally, one must also consider the symbolic significance that the Catholic Church attributes to birth (from the mother's body) as the event through which one becomes human (Anderson, 2024). In this sense, the Church maintains that parents collaborate with God in the creation (and development) of a human being through conception, pregnancy, and, ultimately, birth. Birth also holds anthropological and theological significance. It is seen as a sign not only of our "natural" condition of dependence on others – here, the mother – but also of our helplessness in facing the most significant events of our existence. Additionally, it symbolizes the grace of God, which can be perceived through those who have cared for us and our well-being. Birth is also a biblical metaphor symbolizing the transition from one state to another and can, therefore, represent conversion. According to the Catholic Church, becoming Christian through baptism is a second birth – this time within the body of the Church, which is considered a second mother (Anderson, 2024). The suffering of pregnancy and childbirth also serves as a reminder that humanity is inherently sinful but also that suffering can be temporary and ultimately give way to joy. In this sense, suffering – especially during childbirth – is a metaphor for biblical eschatology. Pregnancy, however, is an experience that has the capacity to bring individuals closer to God. Therefore, contrary to arguments by Kendal (2015), Smajdor (2007), Smajdor (2012), Smajdor and Räsänen (2024), and Firestone (2015), it is not a barbaric and undesirable condition from which humanity should permanently liberate itself. Consequently, resorting to the artificial womb to bring people into the world through technology rather than through the body would deprive future generations of a fundamental event that shapes and defines our perception and understanding of the world.

5 Conclusion

In conclusion, we can affirm that while the official position of the Catholic Church is generally favorable toward the exploration of space, significant moral issues still need to be addressed. The adoption of biotechnologies such as genome editing, assisted reproduction, or the use of artificial wombs, which are in all likelihood necessary so as to ensure human survival and reproduction in space (Braddock and Cahill, 2022), appears incompatible with Catholic moral principles. In particular, genetic modification for non-therapeutic purposes, viewed as an arbitrary redesign of human nature, is firmly rejected by Catholic doctrine. Similarly, although assisted reproduction techniques are potentially indispensable in space, they are deemed morally unacceptable due to the destruction of human embryos, the separation of the unitive and generative acts, and the improper use of sexual organs. Finally, the artificial womb, which could represent a safe, practical solution in space, is judged morally incompatible with respect for human life and procreation. Our conclusion, therefore, is that the Catholic Church still faces the challenge of reconciling technological advances and humanity's ambitions in space with its ethical and spiritual principles. If the only form of space exploration morally permissible is one that does not rely on technologies capable of radically altering human nature (and reproduction), then space risks remaining, in principle, an inaccessible dimension for humanity. Mars and the planets farther from Earth represent the greatest "moral" challenge for the Catholic Church. However, even the establishment of permanent settlements in Low Earth Orbit (LEO) or on the Moon poses significant concerns, as the environmental conditions in these contexts are extremely hostile. Even with the aid of technology to mitigate the effects of reduced gravity (on the Moon, gravity is approximately one-sixth that of Earth) or microgravity (such as that found on the ISS), exposure to cosmic radiation during a prolonged stays in space, travel or over the course of extravehicular activities could damage gametes and embryos, making natural reproduction difficult or risky (Balistreri and Umbrello, 2024).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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