



Synthetic Biology As a Postmodern Technology of Care

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Abstract In recent years, synthetic biology emerged as a potentially ground-breaking biotechnology, promising breakthroughs in healthcare, biodiversity conservation and bioremediation. Combining various technoscientific methods, synthetic biology consists in the application of engineering principles to biology, which is seen as unsatisfactory and perfectible. This methodology makes synthetic biology a postmodern technology of care, namely the political practice of refashioning biology to improve the condition of both human and more-than-human beings. Emphasising the disciplining dimension of care (in the Foucauldian sense of creating ‘docile bodies’), I show that synthetic biology consists in the application of such a dimension to more-than-human lifeforms. That is, I critically highlight how synthetic biology, in its attempt to design novel and functional organisms, seeks to actually produce lifeforms that are ‘ontologically disciplined’ since they possess a simplified and controllable biological structure. The argument I advance in this paper sheds light on how care in the postmodern world is increasingly becoming associated with the simplification of complex biological systems, namely with the production of bioengineered organisms that are fitter to face current global

challenges. Care, therefore, operates as a form of ontological disciplining by inscribing predetermined ways of being within the genetic code of more-than-human organisms.

Keywords Synthetic biology · Biotechnologies · Technologies of care · Postmodernism · More-than-human life

Postmodern Technologies of Care

Among the main features of the postmodern era are the unprecedented and rapid developments in science and technology. Arguably, postmodern technologies respond to utilitarian criteria of efficacy, reproducibility and profitability, to which concerns about verifiability, adequacy, but also well-being, freedom and sustainability are subordinated. These technologies follow the advent of electronic and nuclear power, which replaced early industrial steam power in the post-WWII period, and include “cybernetics, antibiotics, nuclear engineering, television, microelectronics, space travel and later immunology, organ transplants, satellite relaying, and gene splicing” [1]. Furthermore, postmodern technologies epitomise “some of the latest scientific and technological achievements, particularly those that are culturally perceived as ushering in a different historical era and type of society” [2]. As such, postmodern technologies undermine modern canons of universality and human rationality,

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by challenging existing notions of life – from ordinary experiences to the very fabric of biology itself.

The key difference here is that, while both modern and postmodern technologies engage in attempts to manipulate biological systems, the former still rely on *guiding* natural evolutionary processes (e.g., through selective breeding), while the latter entail a more radical intervention aimed at *superseding* such processes through engineered systems [2]. That is, some postmodern technologies circumscribe the complexity and evolutionary patterns of biological systems within the abovementioned criteria of efficacy, reproducibility and profitability. In this regard, advanced biotechnologies using gene editing and genetic modification of organisms have increasingly gained traction in both scientific and philosophical research, as well as in contemporary societies. Among these technologies, synthetic biology has recently emerged as a radical practice with potential benefits for various areas, such as healthcare, biodiversity conservation and bioremediation – among others. Synthetic biology is a multidisciplinary field that combines molecular biology, biochemistry, computational biology and genomics, with the aim of designing new living systems and organisms [3–5]. Accordingly, the postmodern character of the field consists in overextending the modern mechanistic conception of organisms, which in turn become systems that can be constructed, designed and optimised by humans for their particular interests [6].

Such a postmodern character is also evident in the ontological framework within which life is conceptualised by synthetic biologists. As Bensaude-Vincent [7] shows, the field lies on the tenet that “life is information,” whereby organisms (however complex) are seen “as functional units – devices or machines – performing specific tasks,” which in turn are unilaterally directed by human activity. Therefore, in synthetic biology “[n]ature is viewed as a source of programs as much as a source of raw materials” for bioengineering purposes [7]. As I clarify in the remainder of this article, this approach indicates that synthetic biology is not only a standard biotechnology – namely the practice of manipulating biological systems and living organisms to develop specific products such as drugs or foods. Rather, I contend that the field should be understood as a postmodern technology of care.

A key difference exists here: standard biotechnologies such as aerobic fermentation, GMOs, or

biofuels and biocement, aim at harnessing biological systems to address specific and distinct human needs. For instance, aerobic fermentation serves to streamline industrial fermentation processes, boosting the production of key medications like penicillin, while genetically modified crops are engineered to directly confer pest resistance, enhancing food production. As I explain more in detail in the next sections, synthetic biology operates beyond such utilitarian applications of biological processes for addressing human needs, instead identifying and tackling alleged essential biological shortcomings to respond to current global challenges, such as global warming and biodiversity preservation. Such a practice entails an emerging approach to care that is peculiar to synthetic biology.

This argument is particularly relevant for at least three reasons: first, it elucidates some conceptual cornerstones of the field of synthetic biology, underlining its peculiar nature among novel biotechnologies; second, it highlights how the dominant canon of care (broadly conceived) for both human and more-than-human beings is oriented towards tackling the biological imperfection of targeted organisms to respond to global issues; and third, it offers a novel critical angle to problematise the ontological implications of synthetic biology practices concerning human and more-than-human life and organisms.¹

In the postmodern sense, the term ‘technology’ does not merely refer to particular devices or solely to the application of scientific knowledge for specific utilitarian purposes. Rather, postmodern technologies are a constituent element of life and of living practices, blurring the boundaries between organism and machine, living beings and artifacts, mind and body. As Haraway puts it, things (both living and non-living) in the postmodern era are not monolithic entities, but rather compounds: that is, “they are made up of combinations of other things coordinated to magnify power, to make something happen, to engage the

¹ To clarify: I take the notion of ‘more-than-human’ to refer to “the many beings and entities that humans share the planet (and cosmos) with”, including plants, animals, microorganisms and natural systems [45]. Such a notion “speaks in one breath of nonhumans and other than humans such as things, objects, other animals, living beings, organisms, physical forces, spiritual entities, and humans” [46]. This understanding is widely accepted in philosophical debates (but also in HASS debates more broadly) around environmental and technological issues.

world, to risk fleshly acts of interpretation” [8]. Similarly, postmodern technologies are also compounds, being “composed of diverse agents of interpretation, agents of recording, and agents for directing and multiplying relational action” [8]. Such agents can be human and non-human organisms (as parts or as a whole), machines, or a combination of these.

Accordingly, bodies are also a form of technology in the postmodern sense, hence being “an unsettling notion that collapses the conventional binary opposition organism/machine and that renders the meaning and extent of technology undecidable” [1]. As such, postmodern technologies aim at creating specific ways of living, whereby organisms operate like machines, and machines perform organic functions. Foucault identifies the root of such an aim in modern technologies and their “tables and classifications, rankings and norms, examinations and exercises, records and case studies” to “help create obedient, trained, highly productive bodies” [1]. In Foucault’s own words, modern technologies enable “the meticulous control of the operations of the body, which assured the constant subjection of its forces and imposed upon them a relation of docility-utility,” namely a form of discipline [9]. And yet, the postmodern development of such technologies positively extends to social changes both at a local and at a global level [8], while its disciplining dimension consists in the ontological determination of specific ways of living for more-than-human beings at the genetic level. It is in this context that practices of care, such as healthcare, welfare and elderly care, gave rise to so-called ‘technologies of care.’

In these practices, as explained by Webb [10], the notion of ‘technologies of care’ refers to a particular set of skills and processes framed around social justice principles and aimed at delivering services and benefits to those in need. Examples of these technologies include the robotisation of care [11], point-of-care diagnostic tools and testing devices [12], using biosensors for health monitoring [13], and using information and communication technologies to improve the delivery of health and social care services [14, 15]. However, care in the modern sense is ambivalent and paradoxical: as Fox notes [16], “[o]n one hand, [care] is based in intimate and human relations which value giving, love and concern,” while on the other hand, care provides “the basis for disciplinary power and authority” by those who practice care

[see also 17, 18]. In other words, care entails a combination of power and knowledge, aimed at coercing and disciplining the recipients of care.

In this regard, Webb clarifies that modern notions of care “are centred on the power to define appropriate and inappropriate behaviour and set the standards of what is considered normal,” making it “nearly impossible to disentangle [care] from how power in its modern form operates” [10]. Moreover, in the postmodern world, care is firmly tied to a strictly technoscientific form of rationality, whereby the world is understood as composed of either resources to utilise or constraints to overcome in order to achieve particular goals. Healthcare and social care, thus, reflect “this technological way of conceiving how an individual life should be codified, adjusted, modified and determined” [10]. In other words, technologies of care crucially entail “new forms of subjectivity and methodologies of life planning” [10]. Given this totalising technical dimension, the all-encompassing reach of such novel technologies far exceeds the sheer domain of welfare and healthcare services, as is particularly apparent in the postmodern context.

Indeed, technologies of care in the postmodern era generalise beyond human healthcare and welfare, in fact encompassing the more-than-human world too. As Volkart argues, “technologies of care are, in a political sense, about reconnecting to the disconnected Earth, about reappropriating forcibly dispossessed worlds” [19]. She calls this practice a form of counterappropriation, which constitutes an essential condition for a positive environmental transformation that is beneficial for both human and more-than-human beings. In this sense, care also entails the more-than-human world and its biological diversity and involves thinking and acting beyond a merely human standpoint, namely from a planetary perspective that embraces all living beings, humans and more-than-humans. Such technologies, therefore, are “polyphonic, mutable, open, context-specific, yet always directed toward an other [...] allowing us to experience the radical unpredictability of terrestrial being” [19]. Furthermore, the notions of ‘other’ and of ‘terrestrial being’ used by Volkart refer to both human and more-than-human beings.

As I show in this article, this growing attention to caring for the more-than-human world, in the sense described above, is particularly prominent in the field of synthetic biology. As Meacham and Prado

Casanova highlight [6], “genuinely philosophical questions about chemical cognition, the possibility of providing a list of characteristics that could ‘define’ life, the origins of terrestrial life, and the political economy of biomaterials” are essential to the field of synthetic biology. Accordingly, I argue that synthetic biology should be understood as a postmodern technology of care. To support my core argument, in the next section I begin by introducing synthetic biology as a multidisciplinary field aimed at reducing the complexity of biological systems. I then discuss four specific examples whereby synthetic biology is conceived as a postmodern technology of care, that is to say, as a political practice aimed at redesigning biological systems in order to benefit both human and more-than-human beings. Subsequently, I clarify how synthetic biology generalises the disciplining dimension of care beyond particular (human) subjects and applies it to more-than-human lifeforms.

Beyond Biotechnology: Synthetic Biology As a Postmodern Technology of Care

Due to its fundamental challenges to traditional notions of life and biology, synthetic biology presents an “affinity and interaction with philosophical, ethical and political investigations” [6]. At its core, synthetic biology can be defined as the application of engineering principles to biological life, whose purpose is “to make biology into an engineering discipline” [4]. The engineering of biological systems entails the design of pathways and functions that do not currently exist in nature and the streamlining of biological systems into mechanistic and predetermined patterns. Indeed, Calvert further emphasises that “there is a strong rhetoric among synthetic biologists that biology on its own is unsatisfactory, and needs to be transformed into an engineering discipline” [4].

What makes biology unsatisfactory is arguably its inherent uncertainty and unpredictability: that is, biological systems, with their complex structure of interactions between cells, organs and molecules, and with their intricate network of relationships with other biological systems and their environment, are shaped by evolutionary processes that escape human control and mechanic modularity. Contrary to biological systems, engineering models respond to the criteria of efficiency,

reliability and predictability. On these grounds, Calvert clarifies how synthetic biology unifies the desire to understand biological systems and the aspiration to create novel engineered ones. Accordingly, “synthetic biology is not just about creating new things, because creating new things also helps us understand existing ones better” [4]. By better understanding the complexities of existing biological organisms, it will be possible to better grasp and simplify such complexities, hence streamlining the functions of such organisms in a more controllable and predictable manner. As Calvert has highlighted elsewhere [3], not only is synthetic biology “literally constructing nature by building new types of biological entity, but it is also constructing a new understanding of nature by challenging our notions of what is ‘natural.’”

Bensaude-Vincent defines this discipline as a form of “technomimetism,” whereby biological systems are designed emulating artificial devices [7]. This practice is diametrically opposed to biomimetism, which consists in the emulation of the functions of biological and natural systems in engineering and similar technological fields. Synthetic biologists, therefore, conceptualise life “in terms of familiar, man-made machines,” which enables them “to construct rational and reliable artefacts that get rid of all the messiness and unpredictability of natural systems” and “to implement the principles of rational design into natural systems” [7]. Hence, since natural evolution is mainly shaped by contingent circumstances, synthetic biologists regard it as a perfectible process that ought to be redesigned and streamlined by human beings in accordance with an engineering logic.

As mentioned in the previous section, synthetic biology arguably entails an ontological account of living organisms as analogous to engineered machines, defining both entities in terms of the functions they perform. As Coyne [20] explains, a key ontological difference exists here: while the fundamental purpose (*telos*) of machines is entirely superimposed by their human designers, an organism is a self-determining entity whose *telos* is inherent to its self-organisation and metabolism. Simply put, machines have a ‘transcendent’ *telos*, given that their purpose and functions originate in the mind of a human being external to the machine, whereas organisms have an ‘immanent’ *telos*, as their purpose and functions belong to, and originate from within, the organism itself.

In other words, while both engineered machines and organisms are compounds of different parts, a fundamental ontological difference remains, which poses a significant challenge to synthetic biologists. Indeed, while machines are reducible to ‘the sum of their parts,’ insofar as they perform the functions that they have been designed for, the same cannot be said about organisms. As Coyne himself puts it, an organism, being “a process or act of self-organisation, is more than the sum of its parts and – crucially – also generative of them *as parts*” [20]. In this regard, the existence of an organism is always given in relation to the external world, which contributes to its evolution and to the structuring of its biological parts, which in turn cannot be reduced to a sheer series of reproducible functions. Hence, it is no surprise that “synthetic biologists realize the complexity of natural systems through failed attempts at mimicking or overtaking nature” [7].

Accordingly, reducing nature’s biological complexity is crucial for this field. Nevertheless, besides the “*form or manifestation* of the drive to mastery [over nature], granting as it does the power to refashion living beings according to [human] desires” that Coyne [20] highlights, there is another dimension to synthetic biology, which requires deeper problematisation. Indeed, the ability to manufacture predictable, reliable and controllable organisms is key, insofar as such organisms can be used to respond to global challenges faced by humankind – including access to healthcare, biodiversity conservation and climate change. In other words, synthetic biologists are arguably motivated by, and ultimately aim at, achieving the good of humankind through the engineering of novel simplified organisms. Such a claim is quite problematic, raising important ethical questions about who gets to determine what ‘the good of humankind’ is in the first place [21] or about potential risks and misuses of the science for nefarious purposes [22].

As these issues have already largely been discussed in existing scholarship [see also 23, 24, 25, 26], here I intend to critically shed light on how synthetic biology strategies, practices and applications, originating from such a problematic assumption, characterise the field as a postmodern technology of care, as defined in the previous section. Indeed, reducing the biological complexity of micro and macroorganisms requires direct interventions on natural evolutionary processes, hence attempting

to make biological evolution a process induced and directed by humans [5]. It is through such interventions that synthetic biology can achieve its goals and benefit both human and more-than-human beings. Consequently, it is through the pursuit of such goals by way of its practices that synthetic biology can be defined as a postmodern technology of care.

This argument is not meant to downplay the political implications of synthetic biology in relation to its socio-economic, ethical and political dimensions, nor to reduce such implications solely to the technomimetic mindset of some of its proponents. Undeniably, synthetic biology has already spread its influence beyond the field of technosciences to humanities and social sciences, by introducing key concerns on biosafety, biosecurity, ethical issues (e.g., around the deliberate genetic manipulation of life) and sustainability in contemporary debates [27]. Rather, my argument sheds further light on such political implications: while ethical and biosafety concerns are already significant in debates around synthetic biology, highlighting the field’s peculiar paradigm of care allows us to better grasp its conceptual core and envisioned future trajectory.

On these grounds, I now discuss four specific examples of synthetic biology applied to drug production, biomedicine, biosecurity, biodiversity conservation and bioremediation, as they best illustrate how such a science is in fact a postmodern technology of care. That is, I contend that these examples (although some of them only refer to potential applications of this science) clearly show how synthetic biology entails a political practice of reconnection with, and reappropriation of, the disconnected more-than-human world (as per Volkart’s terminology) – while at the same time generalising the disciplining dimension of care to the more-than-human world. To clarify, I am not suggesting that synthetic biology is fundamentally distinct from standard biotechnologies; rather, I am suggesting that its core practices, while being akin to those of novel biotechnologies, are better understood as a postmodern technology of care. In doing so, I also critically emphasise the fundamental ontological premise of the field, whereby more-than-human organisms are conceived as perfectible biological entities, rather than as *stricto sensu* equivalent to machines.

Semi-Synthetic Artemisinin

Synthetic biology can be used to create a semi-synthetic version of artemisinin, an antimalarial drug derived from the *Artemisia annua* plant. Here, an ad hoc yeast is engineered to produce high levels of artiseminic acid, hence providing a cheaper and abundant source to produce antimalarial drugs [28]. The production of semi-synthetic artemisinin is generally considered as “the first success story for the combined use of metabolic engineering and synthetic biology in the production of a pharmaceutical agent at industrial scale” [29]. Despite its high production costs and currently limited market uptake, this case is particularly interesting, since it constitutes a basic example of synthetic biology as a postmodern technology of care.

Semi-synthetic artemisinin is seen by some of its proponents as a clear indication that “[t]he inception of synthetic biology in medical applications is now becoming unstoppable” [30]. This enthusiastic statement testifies not only to how this science is particularly valuable for the pharmaceutical industry, but also that synthetic biology is better understood as a postmodern technology of care. Beyond the obvious manipulation of a targeted microorganism for industrial and commercial purposes, there is in this science an equally clear element of care in the postmodern sense. That is, bioengineering yeast in order to generate a greater and arguably more reliable source of artiseminic acid entails a production of a biological compound (i.e., a body) with a specific and predetermined function. In other words, producing additional and abundant levels of artiseminic acid is in fact achieved through a meticulous codification, adjustment, modification and determination of the yeast’s life and functions, in line with Webb’s abovementioned notion of care. In other words, bioengineering here is a practice of care aimed at imposing a relation of docility-utility (as per Foucault’s terminology) on a more-than-human microorganism.

Therefore, such a technology is inherently postmodern because it redesigns the genetic fabric of yeasts and imposes an allegedly reliable, predictable and controllable level of production of artiseminic acid on them. This way, such microorganisms will not only guarantee higher profitability and functionality for a specific industry sector, but also have a form of *ontological* docility, inscribed in their very genetic

code. Commenting on the ethical issues arising from the production of semi-synthetic artemisinin, Dalziell and Rogers [31] note that “creating novel, artificial organisms changes the symbolic relationship between humans and the natural world in significant ways.” Such a change, I contend, should be understood as the production of disciplined more-than-human organisms in the postmodern sense described in the previous section.

To clarify, I argue that synthetic biology emerges here as a postmodern technology of care insofar as the redesigning of particular organisms is aimed at delivering care and at generalising the disciplining dimension of care beyond human subjects. That is, synthetic biology is here used to produce docile more-than-human bodies in order to provide care for human subjects. Unlike modern notions of care, the key element here is that the docile bodies are not the recipients of care, but rather the means through which care is delivered to human subjects. This entails a form of care whereby care itself is delivered *through* – and not *to* – a docile body. Herein, the docility-utility of the engineered yeast, namely its capacity to produce abundant artiseminic acid for drugs production, tackles the original ontological imperfection of traditional yeasts, unable to perform the same functions as the bioengineered one. Hence, such an intervention operates at a more fundamental ontological level than traditional practices of care as discipline – whereby the docile bodies are those of the human recipients of care.

In other words, care is here provided by grappling with the uncertainty of biological organisms through synthetic biology: against “the radical unpredictability of terrestrial beings” [19], bioengineered yeasts are redesigned with the fundamental task – namely, ontologically inscribed in their DNA – of leaving behind the irregular production of artiseminic acids of traditional yeasts and plants. This way, the imposition of (human) power and knowledge over more-than-human beings is aimed not at disciplining the recipients of care, but rather at redesigning more-than-human lifeforms so that care for human subjects can be provided more efficiently. This practice, I maintain, constitutes a clear postmodern development of technologies of care, and of the dominant canon of technical rationality described by Webb, finalised at ontologically determining the specific functions of an organism as a means to deliver care.

Engineered Smart Cells and Living Therapeutics

The applications (either potential or actual) of synthetic biology to the healthcare field are not limited to Artemisinin alone, but rather count numerous other biomedical examples. Indeed, such applications include “engineered smart cells, live probiotic therapeutics, diagnostics, stem cells, drug production, nanocarriers and artificial vaccine developments” [32]. For instance, specific cells can be engineered to target cancer cells or to prevent metabolic diseases by modifying the metabolic flux in human recipients. Similarly, synthetic biology provides methods to generate synthetic gene networks, bioengineered tissues and cells, and analogous “programmable organisms” that could be used both for diagnostic purposes and for tackling the biological mechanisms that underlie specific metabolic or genetic diseases. Bioengineered cells have the potential ability to develop more effective immunotherapies, by enhancing targeted drug delivery compared to traditional drugs administration. While these applications have shown some effectiveness in terms of therapeutic outcomes, they are still in their early stages and only a few of these have entered the clinical stage [32].

Nevertheless, engineered cell therapeutics are rapidly spreading in the biomedical field, and synthetic biology plays a crucial role in such an expansion. In particular, synthetic biology enables the design of synthetic gene circuits – that is, networks of living cells interacting with each other – with the goal of generating so-called Engineered Living Therapeutics (ELT). As explained by Cubillos-Ruiz et al. [33], “[h]uman and microbial cells can be genetically modified to correct intrinsic defects or to unlock their full therapeutic potential” through synthetic biology. They also note that, while there have been notable advances in the field of synthetic biology that can address the limitations of traditional therapies – such as “lack of flexibility, specificity and predictability” [33] – further research is required before greenlighting the full implementation of ELT as human therapeutics.

The key element here is, once again, the aspiration to redesign biological systems and to circumvent the alleged ontological limitations of traditional biology. Specifically, ELT and other bioengineered therapeutic cells are programmed to execute a variety of therapeutic actions in response to different chemical, biological or environmental signals, instead of targeting

one single disease-associated cell or molecule at a time, like traditional therapeutics. Such a flexibility is also integrated with the specificity of responding to multiple disease indicators, enhancing therapeutic outputs. Ultimately, ELT are aimed at providing more predictable and controllable therapeutic outcomes, in contrast with the unpredictable outcomes of traditional therapeutic approaches, which are less flexible and adaptable to biological and physiological variations among patients, or to the dynamic nature of disease states within each patient [33].

Beyond the provision of healthcare through bioengineered cells and organisms, a further component that is inherent to postmodern technologies of care emerges here, namely that of addressing the alleged shortcomings of traditional biology through the design of novel predetermined biological patterns. That is, care here clearly becomes a matter of designing and controlling the biological functions of particular cells or even microorganisms, so that the human end-users can receive care. Therefore, care is intended to build a “technological compound of conjoined forces,” that is “a composite of individual organisms,” borrowing again from Haraway [8]. Furthermore, she continues, “one of the meanings of compound is ‘an enclosure, within which there is a residence or a factory’ – or, perhaps, a prison or temple” [8]. In other words, care in the postmodern sense is provided through a technological rearrangement of the interrelation between living organisms (both micro and macro), by introducing bioengineered life-forms, designed to follow specific and predetermined pathways, into existing biological frameworks. While bioengineered yeast for semi-synthetic artemisinin had the basic task of increasing the production of artemisinic acid, the case of ELT and smart cells showcases how such modified biological systems, due to their improved and perfected ontological nature, act directly on the human recipients of care.

Synthetic biology, then, well illustrates how care becomes tied to attempts to manage, control, and even remedy the inherent uncertainty and ontological imperfection of biological systems. That is, in response to such unpredictability and imperfection – that synthetic biologists find unsatisfactory – care becomes associated with the implementation of a genetically predetermined way of living for specific microorganisms, namely a way of ontologically disciplining them in terms of docility-utility for

the benefit of human end-users of care. Rather than sheer machines, the targeted organisms are regarded as ontologically flawed entities, hence unable to perform the required functions. Therefore, by correcting their genetic fabric through human design, they become ontologically predetermined to deliver care to human end-users. However, as already mentioned above, postmodern technologies of care are not limited to healthcare, but rather encompass a wide range of applications that relate to the more-than-human world. As I show in the following sub-sections, synthetic biology is no exception to this tendency, and actually exemplifies it.

Gene Drives and Genetic Biocontrol for Biosecurity

Another, although quite different, example of providing care through synthetic biology is the existing research into gene drive technology and gene editing. Through these practices, synthetic biology offers a potential application to major biosecurity threats, such as the spread of harmful viruses or pests [34]. Indeed, by enabling selected genetic traits to spread more rapidly than normal in targeted populations, synthetic biology can potentially be a key element in the eradication of invasive species and vector-borne diseases. Biocontrol of malarial mosquitoes is perhaps the best-known example of this practice. Here, genetic biocontrol is proposed to significantly alter the genetic traits of malarial mosquitoes, preventing them from reproducing and eventually eliminating their population in affected areas.

In particular, synthetic biology enables the use of so-called Sterile Insect Technique (SIT), aimed at preventing the production of viable offspring in malarial mosquitoes [35]. Herein, genetically engineered sterile male mosquitoes are released within the existing population, “induc[ing] sterility in females via the production of unfertilized progeny” – which in turn “dramatically reduces the overall density of the targeted population” [36]. As of 2024, there are 42 ongoing projects of mosquito eradication using SIT, which demonstrates the widespread potential impact and outreach of such technique [36].

Gene editing is also being explored to combat invasive rodent populations on small islands (such as Lord Howe Island), which pose a major threat of

extinction to endemic species. Here, this practice is explored to spread specific engineered transgenes that will lead to the collapse of the invasive species within a few years [37]. Even in this case, using gene drive and synthetic biology is seen as a crucial complementary practice to other eradication efforts, such as hunting, trapping and poisoning, in order to ensure the total suppression of the targeted invasive species. Gene editing is therefore a very powerful tool to control, reduce and eliminate targeted populations of pests or other parasites, and has been proven effective on flies, mosquitoes, yeast and mice.

Gene editing, however, requires highly efficient, detailed and exhaustive computational models that can account for all potential real-world outcomes and applications of such techniques with as much accuracy as possible [37]. In other words, such models attempt to encapsulate the high complexity of the biological systems where modified genetic traits would be implemented. Needless to say, inherent to each of these models is a remainder of biological complexity – namely, that there is always some level of risk that some of the unintended consequences of gene drive practices may materialise. Nevertheless, techniques like SIT are still regarded “as a gold standard for genetic biocontrol interventions for some species” [36]. As mentioned above, the goal of synthetic biology is that of gradually eliminating the uncertainty and complexity of biological systems, and replace them with the reproducibility and modularity of engineering systems – and of ultimately improving the human condition. As Mäkelin puts it, a key feature of gene drive techniques is that “bioscientists also produce understandings of biotechnology and how it manages uncertainty” [38].

Genetic biocontrol can also be intragenerational, namely aimed at directly impacting current generations of targeted species, and not their offspring. Through the so-called Toxic Male Technique (TMT), genetically engineered pest insects express a specific venom protein within the male reproductive system that will significantly reduce the lifespan of mated females. Such a technique could therefore be particularly valuable to combat outbreaks of disease vectors and agricultural pests, and is particularly effective on disease carriers such as black flies and horse flies [39]. Given the major threat that insect pests pose to human and environmental health, gene editing practices such as TMT are presented as a novel way to

deliver tangible care benefit to both human and more-than-human beings, without the health and environmental harms of traditional techniques such as insecticides and pesticides.

Once again, synthetic biology emerges as a political practice aimed at producing docile more-than-human bodies that will follow a predetermined pattern – in this case leading to the eradication of malarial mosquitoes (or other invasive species) in targeted areas. In other words, synthetic biology practices entail an attempt to coerce those more-than-human lifeforms into specific and predetermined ways of functioning, in contrast with the uncertainty and unpredictability of traditional biological systems. Care here is not only paradoxical (as per Fox's definition above) but also manifold. The end-users of such care are both human beings, whose chances of contracting diseases such as malaria are significantly curtailed, and more-than-human beings, as eradicating invasive species considerably alleviates the threat of extinction posed to endemic species. However, care is here still delivered through a third type of more-than-human docile body, namely the bioengineered organisms whose task is to eliminate identified threats to the end-users of care.

In the cases of gene drive and genetic biocontrol, a specific kind of dissatisfaction with biology itself emerges, while maintaining the same ontological assumption about organisms as perfectible entities. That is, the dissatisfaction lies in the fact that natural evolutionary processes actually provide fertile ground for the survival of invasive species. Hence, the inherent unpredictability and ontological imperfection being addressed here are that of entire ecosystems, whereby invasive species thrive at the detriment of endemic ones. Therefore, gene drive and genetic biocontrol target the unsatisfactory and unpredicted course of natural biological evolution: it is not particular organisms that need to be perfected (as per the example of artemisinin yeasts), but rather the evolutionary processes within specific ecosystems.

Furthermore, synthetic biology appears here as a radical attempt to reconnect with the disconnected more-than-human world, as per Volkart's phrasing. That is, the genetic redesigning of particular lifeforms here notionally operates as an endeavour (as questionable as it may be) to remedy to various threats to human and non-human species. Indeed, given the enormous difficulties involved in removing the threat

of extinction due to the spread of diseases or runaway climate change, it appears paradoxically preferable to alter the genetic fabric of targeted species of micro and macroorganisms (and hence of their ecosystems) to make them fit to survive such threats – and to help other species to do the same. Volkart's 'reconnection,' therefore, is operated not through a return to an original state of things, but rather through the manufacturing of novel biological pathways, modelled against postmodern canons of engineering and care.

Biodiversity Conservation and Bioremediation

A fourth and very significant example of synthetic biology as a postmodern technology of care is its potential use for biodiversity conservation purposes, as in the case of the *Chelonia Mydas* sea turtles on Raine Island. Rising levels of global temperatures pose a major threat to the survival of said turtles, by unbalancing their sex ratio and capacity to incubate eggs. Although they are sea creatures, *Chelonia Mydas* turtles normally lay their egg on shore and incubate them under the sand. During incubation, cooler sand temperatures produce more male hatchlings, while warmer temperatures produce more females: hence, global warming obviously leads to higher sand temperatures and to female-only offspring being produced, also increasing the risk of egg mortality [40]. Current attempts to rebalance the turtles' sex ratio include so-called beach reprofiling, namely an artificial pulling back of the beaches where turtles lay their eggs, with the goal of lowering the incubation temperature and hence having a greater number of male offspring [41]. However, more radical interventions seem to be necessary to avoid the extinction of *Chelonia Mydas*.

Synthetic biology offers a potential contribution to such radical interventions. As Wodak explains, the science "would entail discovering the genes that assign sex according to temperature, modifying them, then using gene drives to get the modification inherited across generations" [42]. While such an application is only hypothetical to this day, it might soon become the quickest and best option to effectively prevent the extinction of *Chelonia Mydas* sea turtles. Borrowing again from Wodak:

It is here, in bioengineering as conservation, that the stakes find their fullest expression in risk, complexity and uncertainty: intervening directly into evolution itself to forestall extinction. Such interventions are about catalysing effectively instantaneous phenotypic and/or genotypic modification for future descendants to inherit the modified traits. Say a discernible phenotypic or genotypic trait takes ten millennia to appear across a species, and scientists induce a discernible inherited trait in ten years in a population of the species. From an evolutionary time perspective, that is effectively instantaneous [42].

This form of bioengineering for biodiversity conservation is a fully-fledged postmodern technology of care. Once again, care is delivered through the genetic refashioning of more-than-human organisms. Moreover, the alleged benefits of such care are exclusively more-than-human, as they only apply to *Chelonia Mydas* sea turtles. That is, the assumption is that only by intervening on the turtles' genetic traits – and hence determining their way of living in a very specific manner – will it be possible for them to avoid extinction and survive global warming. Instead, 'undisciplined' sea turtles – namely those turtles whose genetic traits have not been altered through synthetic biology – would be unable to survive global warming and carry on their species. In other words, altering the turtles' DNA and evolutionary trajectory is not merely a reduction of complex organisms to specific functions (such as breeding, reproduction and transmissions of genes), but rather an essential alteration of said functions to tackle an ontological imperfection that would otherwise lead the species to extinction.

This is also a unique example of reconnecting with the disconnected more-than-human world, as it constitutes a radical attempt to preserve and protect such a world against the harms that human beings have generated in the first place. That is to say, synthetic biology here constitutes a potentially novel "planetary mode of existence" [19] to grapple with the instability of traditional biological systems, as exemplified in the inability of *Chelonia Mydas* sea turtles to adapt to the increasing rates of global temperatures. When radical uncertainty concerns the survival of entire species, then attempting to tackle it through a more

predictable and functional bioengineered structure becomes the epitome of the latest development of postmodern technologies of care. In response to planetary and existential issues such as biodiversity loss and climate change, care becomes achievable and deliverable only through the genetic manipulation of particular more-than-human beings. In other words, care at a planetary level is increasingly dependent on the human ability to coerce more-than-human beings into specific ways of being through function-specific modifications of their DNA structure.

An analogous example is the potential use of synthetic biology for bioremediation. Herein, ad hoc bioengineered microorganisms could be produced in order to boost the degradation and removal of various contaminants, pollutants and toxins from the environment. Building on the natural capacity of bacteria, fungi and microbes to degrade environmental pollutants, novel microorganisms with a genetically altered microbial strain could be produced, having a significantly higher capacity to decompose harmful environmental waste. Indeed, "[a]side from engineering of bacteria, [synthetic biology provides] many other methods for manipulating a plant, animal, or microorganism's genetic sequence, all of which are based on a specific goal," which in this case is environmental bioremediation [43]. These bioengineered organisms are then expected to provide a key contribution to the health and safety of global environments and to benefit both humans and more-than-human beings.

Thereupon, it once again becomes apparent how the postmodern notions of care outlined by Volkart and Webb converge in the application of engineering methods to biological systems. That is, the genetic engineering of microorganisms to degrade environmental pollutants, as well as of macroorganisms to carry on their species against the threat of global warming, is perhaps the ultimate iteration of the postmodern technologies of care. Indeed, such forms of bioengineering typify both Volkart's process of designing specific biological functions in a laboratory ("going out of oneself"), applying those designs to living organisms ("connecting"), releasing such organisms in the external world ("becoming collective") and hence altering traditional evolutionary processes ("exceeding the mark"), in order to provide specific benefits to both human and more-than-human beings ("coming back to oneself") [19]. At the same time, synthetic biology also consists in the

establishment of new forms of subjectivity and life planning (as per Webb's analysis) even at the more-than-human level, by genetically imposing predetermined ways of living (namely, an ontological disciplining) on various micro and macroorganisms, in an attempt to deliver tangible care to both human and more-than-human beings in response to global crises.

In this regard, care in the postmodern sense, as aptly exemplified by synthetic biology, increasingly takes the form of a critical resource to the tackle the abovementioned global issues by disciplining more-than-human lifeforms. In other words, while such issues have been mainly generated by human activity, the inherent unpredictability of traditional biological systems is now seen as unfit to face those issues – hence why bioengineering novel lifeforms that are arguably more reliable and predictable is seen as a potential and desirable response, and as the emerging paradigm for delivering care to human and more-than-human beings. Once again, what emerges here is not a sheer equation of micro and macroorganisms with machines, where only their functions are what constitute them. Instead, traditional biological systems appear once again unsatisfactory qua flawed, ontologically imperfect and in need of streamlining and improvement through human interventions. As these systems are unreliable compounds, humans set themselves the task of designing better and fitter compounds, which in turn maximise the functionality of a machine while maintaining the malleability of biological systems (be it to further human interventions or to evolutionary processes).

Conclusion: Postmodern Care As Genetic Disciplining

As demonstrated by the various examples discussed above, synthetic biology plays an increasingly important role in contemporary debates around global issues. Therefore, it is paramount to critically assess the potential impact and the problematic aspects of this science, which I have attempted in this paper. As the above discussion illustrates, synthetic biology is better understood as a postmodern technology of care, rather than as a standard biotechnology. In this regard, synthetic biology upholds a form of care whereby care itself is provided through the genetic manipulation and redesign of specific micro and

macroorganisms, and of traditional evolutionary processes. Therein, care is conceived as a way to respond to global crises or challenges by making targeted lifeforms fitter to survive such crises or challenges through the alteration of their genetic fabric.

Proponents of such a technology argue that “personalized engineered medicine is the next-generation treatment strategy in the future” and that “[s]mart therapeutics based on genetic-encoded circuits that can interpret environmental signal into effector activities will be commonly used” [32]. Indeed, it is in practices of care in the postmodern sense that synthetic biology is already being concretely applied. Besides the abovementioned examples of semi-synthetic Artemisinin, currently ongoing projects on SIT methods, there are a number of other biomedical products already available that are being produced using synthetic biology [44], further demonstrating the validity of the main argument of this paper. The appeal of such applications of synthetic biology lies in their impact (whether effective, promised or perceived) on such challenges.

Synthetic biology emerges therefore as an ever-growing practice of coercion and discipline for more-than-human beings in response to global challenges that affect both human and more-than-human lifeforms. Furthermore, such a practice operates at a more fundamental level than modern approaches to care: that is, it is a form of ontological coercion that imposes predetermined ways of living to specific cells, micro and macroorganisms, by inscribing these ways in their genetic code. Accordingly, as this paper has shown, such an ontological disciplining at the genetic level becomes the kernel of care through synthetic biology: in fact, such care is associated with the simplification of complex biological systems, namely with the alleged predictability and controllability of the functions that such genetically disciplined organisms will perform. While this practice does not entail a strict ontological equivalence between organisms and machines, the focus on refashioning an organism's DNA to implement specific functions and purposes indicates that biological organisms are regarded as imperfect systems requiring optimisation through human interventions. Accordingly, the goal is to produce compounds that are able to both streamline the performance of specific organic functions (like

machines) and remain susceptible to external influences (either human or more-than-human).

In conclusion, the political reappropriation of and reconnection with the more-than-human world, that Volkart identifies as the essence of postmodern technologies of care, translates into genetic disciplining, that is to say into a coming to terms with the inherent unpredictability of biological systems. And yet, such terms are inevitably the *human* terms of ad hoc designed biological pathways for more-than-human beings. Arguably, after human activities generated the abovementioned challenges that jeopardise the well-being and survival of more-than-human species, synthetic biology as a postmodern technology of care provides a radically overbearing approach aimed at coercing more-than-human beings into enduring such challenges. Whether or not such an approach will be beneficial for the human and more-than-human world broadly conceived, as synthetic biologists admittedly promise, will be determined in the (not too distant) future.

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Declarations

Ethics Approval and Consent to Participate Not applicable.

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