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Biomimicry and AI-enabled Automation in Agriculture. Conceptual Engineering for Responsible Innovation During Climate Change

Abstract

This paper aims to engineer the concept of biomimetic design for its application in agricultural technology as an innovation strategy to sustain non-human species' adaptation to today's rapid environmental changes. By questioning the alleged intrinsic morality of biomimicry, a formulation of it is sought that goes beyond the sharp distinction between nature as inspiration and the human field of application of biomimetic technologies. After reviewing the main literature on Responsible Innovation, we support Vincent Blok's "eco-centric" perspective on biomimicry, which considers the human and natural worlds as indistinguishable parts of a shared Earth. We propose this approach as a complement to the "evomimetic" critique, which warns biomimetic research against the limits of adaptationism. By merging these two reframing of the biomimicry concept, we thus pave the way for a new understanding of the use of human-inspired technology (such as Artificial Intelligence) to help the "evolution" of domesticated species into (semi)autonomous natural-technological hybrids. In particular, the examples we consider concern the potential of AI-enabled robotic bases in technological beekeeping.

Keywords

Biomimetic Design, Conceptual Engineering, Responsible Innovation, AI in Agriculture, AI-enabled automation, Technological Beekeeping.

1. Introduction

According to Janine Benyus (2002), biomimetics is "a [relatively] new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems". Over the years, this phrase has been quoted countless times in articles that have delved into this issue and revealed, among other things, its possible applications, its specific position in the history of techniques, and the theoretical and philosophical assumptions behind it. Characterised from the outset by clear ethical connotations, these have been notably deepened in recent years, also in connection with the topic of Responsible Innovation. This article aims to build on these analyses to propose a new perspective, starting by questioning the intrinsically ethical aspect attributed to this innovation strategy along the lines of other attempts to redefine biomimicry. In particular, we will try to understand how this concept can be adjusted to address technologies that may be applied to living organisms or systems, especially in an agricultural context, to compensate for the difficulty of natural selection in keeping up with the rapid changes in the ecosystem during global warming (Varshney et al., 2011). Some criticisms levelled at biomimicry, such as the "evomimetic" and "paleomimetic" ones presented in §2.2, have warned against using evolution as a source of optimal solutions, as many forces other than adaptation are at play. These critiques will be the starting point for seeking a new conceptualisation of biomimicry that identifies humans and nature indistinctly as models and targets. In §3, we will investigate the different possibilities of conceiving technology that exist in philosophical research on Responsible Innovation to focus on its ontological understanding informed by the dynamics of the Anthropocene, with its questioning of the dichotomy between the human and natural worlds. Thereby, the "evomimetic" critique will be implemented (in §4) with an "eco-centric" perspective, which invites biomimetic design to consider natural-technological hybrids that can adapt to the ecosystem, treating humans and nature as parts of the same Earth (or "Gaïa", as in Latour, 2015).

A practice such as biomimetic design, inspired by the adaptation strategies of different organisms to their environment, could suggest implementing a feature of one species in a technological-natural hybrid involving another one to help the latter cope with climate change by compensating for its evolutionary limitations. An example, though not directly related to environmental issues, might be the thermal treatment, similar to fever in humans and other animals, to rid honeybee hives of *Varroa destructor* without chemical pesticides (Bičík, 2016). Another aspect that would be incorporated into the biomimetic field by this re-conceptualisation is that of AI-powered robots in agriculture, which are more closely related to the search for solutions to new environmental challenges. In these cases, the feature imitated by this innovative technology and applied to another organism or population, e.g. a colony of honeybees, is human intelligence, which is emulated in its ability to analyse the available data and autonomously formulate decisions on how to respond to unprecedented circumstances.

Therefore, this article intends to modify the concept of biomimicry to include a horizon of application that, although it is of utmost urgency, is not commonly considered. Unlike the "evomimetic" critique, which is a correction of the concept based on the analysis of its formulation, this article follows the trail of the so-called Conceptual Engineering. It is defined as "a branch of philosophy concerned with the process of assessing and improving our concepts" to achieve "certain beneficial consequences" (Isaac et al., 2022). According to the "dominant narrative", whereas conceptual analysis has a descriptive character, conceptual engineering has a prescriptive one, indicating how a concept should be reformulated (Isaac et al., 2022). This choice is based on specific practical interests and moral values (Löhr, 2023), but to what extent conceptual engineering and conceptual ethics can be linked to each other is still debated (Cappelen & Plunkett, 2020). It should be specified that, in this case, this practice does not result from a "conceptual disruption" caused by the advent of new technologies and from the consequent demand for new conceptual reference points to orientate in a brand-new landscape (as happens in other instances, see Hopster, Brey et al. 2023). On the contrary, this reframing stems from the need to improve the concept of biomimetic design in favour of specific branches of ecological innovation. According to Blok (2022a), in fact, "to advance theory and practice in the interdisciplinary field of biomimicry", philosophy can question "dominant conceptualizations", clarify "conceptual ambiguities", and engage "conceptual engineering".

2. Concepts of biomimetics

Janine Benyus's book *Biomimicry: Innovation Inspired by Nature*, which popularised this concept in 1997, paved the way for an innovation strategy that considers the "natural system as inspiration rather than as resource" (MacKinnon et al., 2020). Beyond this goal, which paraphrases the book's title, hides a vast number of issues, distinctions, and clarifications, as the many articles written on the subject over the last twenty years reveal. We should probably start from the distinction between the terms "biomimetics" and "biomimicry", which often occur interchangeably in the writings on this subject, also for the possible use of "biomimetic" as an adjective for "biomimicry" (MacKinnon et al., 2020). Whereas the term "biomimetics", coined by Otto H. Schmitt in 1969, "represents the studies and imitation of nature's methods, mechanisms and processes" (Bar-Cohen, 2006). biomimicry intends to leverage this attitude to move from a condition of exploitation of nature to one of exploration (Benyus, 2002). In other

words, in contrast to biomimicry, approaches such as biomimetics and bionics do not necessarily focus on sustainable development and instead concentrate on merely replicating innovative functions (Gerola et al., 2023).
We can also come to the same conclusions through the terminological analysis of this issue in Fayemi et al. (2017). Here, the terms "bioinspiration" and "bionics", equally present in the scientific literature as synonyms, are also considered. In this study, we can find how the definitions of "biomimetics" and "biomimicry" overlap with regard to the shared abstraction of nature into transferable models suitable for technological innovation. However, "biomimicry" differentiates itself from the former term for its stated aim of addressing the challenges of sustainable development (in its social, environmental and economic aspects). Biomimicry can be considered one of the main strategies through which we are currently approaching the target of a Design for Sustainability, together with the cradle-to-cradle and the Circular Economy perspectives (Wever & Vogtländer, 2015).
Furthermore, in recent years, additional subdivisions have been proposed within biomimicry itself. According to Goldstein & Johnson (2015), "[a]s a field, biomimicry is diverse and, at times, less than coherent. Its practitioners can scarcely agree on the term's definition, on what level of fidelity to nonhuman life is required for a project to count as 'biomimesis' or to what ends its methods are best applied". Of particular relevance are the distinctions developed by Vincent Blok and his colleagues, which we briefly review here. A first demarcation suggested by Blok & Gremmen (2016) divides the concept of biomimicry into a "strong" and a "weak" formulation. According to the two authors, "[t]he strong concept of biomimicry is represented by Janine Benyus. She conceptualises biomimicry in a naturalistic way as an imitation of nature's models in order to solve human problems". In this context, nature is seen as a some-4-billion-years R&D lab that has solved many of the issues we are coping with today (Benyus, 2002; Blok & Gremmen, 2016). According to a dichotomy criticised in the authors' text, such a strong concept of biomimicry explicitly pushes towards the "discovery" of new technologies through the imitation of natural mechanisms rather than the "invention" of artefacts. Blok's and Gremmen's criticism on this point stems from the fact that mimesis, understood in Aristotelian terms, also contains a character of differentiation from the model. Our epistemological limitations in understanding the natural system we want to echo imply this difference. According to the "weaker, but more sophisticated concept of biomimicry", with which the authors attempt to remedy the criticism of the former, "mimicry does not consist of the reproduction or duplication of natural solutions; rather, these natural solutions are taken as inspiration to create new materials and devices" (Blok & Gremmen, 2016). As in the previous case, nature is seen as "a catalogue of products" (MacKinnon et al., 2020) or "a living encyclopaedia of ingenuity" (Taylor Buck, 2017). The difference is that "the weaker concept does not take natural principles as a normative standard, but focuses on the re-creation of nature for human ends" (Blok & Gremmen, 2016).
In other words, the patterns found in nature are seen as a source of inspiration from which to draw at will, combining or modifying them according to the needs of the case. Although useful in its clear focus on two different attitudes, this distinction between strong and weak formulations was later criticised in a 2023 article contributed by Vincent Blok himself (Gerola et al., 2023). At the heart of this critique was a problem found in Blok and Gremmen's argument, namely the unclear distinction between inspiration and copying, which needs to be reflected in the actual design practices. The authors' proposal is an attempt to reclassify what they comprehensively call "biomimetic design" (encompassing under this term any design approach that takes nature as its source of inspiration) to highlight the different conceptual and normative assumptions of its various possible declinations. Although this investigation proves to be of considerable interest, our article will focus again on the specific typology described under the term "biomimicry" to understand how reframing this innovation strategy through a

Conceptual Engineering approach may positively affect its ethical performance. In these terms, our analysis is intended to fit into the strand of Responsible Innovation.

2.1 Biomimetic promises

As John O'Neill et al. (2008) point out, the notion of "natural" as opposed to "artificial", on which the concept of biomimicry is based, is a concept historically codified. According to them, "[t]here is no such thing as a state or condition of something which constitutes its 'being natural' or an identifiable set of characteristics which makes any item or event 'natural'" (O'Neill et al., 2008). This uncertainty also applies to agriculture, to which we will refer more extensively below, as Paul Thompson points out in the opening of *Philosophy of Agriculture Technology* (2009). In this sphere, we find several attempts to categorise the different meanings of the term "natural", both with regard to the distinction between organic farming and other practices (Verhoog et al., 2003), and to clarify its use in food production (see, for example, Sagoff, 2001 and Siipi, 2013). In her attempt to analytically classify the different dimensions of "naturalness", Siipi (2008) emphasises how its various meanings are used in different ways in "bioethical argumentation", following whatever the intentions of the case may be. The entities at the centre of these discussions, "such as GMOs and different types of ecosystems", can be considered natural from a given point of view and unnatural from another. Hence, we need to clarify the precise use of these connotations on each occasion so as to avoid "forms of bad argumentation, or at least vagueness" (Siipi, 2008).
Moreover, the term "nature" is not only "*overdetermined* (defined in various ways) and *underdetermined* (no single definition seems adequate)," but is also commonly used as a "thick concept," i.e. a concept with not only a descriptive but also an evaluative and normative character (Hopster, Gerola et al., 2023). As the long-standing debate between Stuart Mill and Ralph W. Emerson (among many others) testifies, there is nothing intrinsically positive or negative in the concept of nature, that is, nothing that indicates a moral value in acting in accordance with it (Rolston, 1979) – as well as in opposition to it, as advocated by William James (James, 1911). However, there is an overall consensus in today's Western societies that nature and naturalness are generally positive factors to be promoted, especially in the ecological awakening related to environmental issues. This leads to the so-called "conceptual appropriation" of NATURE in discussions of the most recent technological solutions to "make a value-laden claim" to them (Hopster, Gerola et al., 2023). This is the case, following the examples of the article by Hopster, Gerola et al. (2023), of solar geoengineering, cellular agriculture, and, indeed, biomimicry as nature-inspired innovation.
With the term "biomimetic promise", von Gleich et al. (2010) highlight the fascinating aura the discourse around biomimicry confers to this innovation strategy. This term refers to the expectations that bind bio-inspired research fields such as bionics, biomimetics, and biomimicry to a sustainable path of innovation in its ecological, economic, and societal spheres. Biomimicry's goal to change our way of valuing nature (Dicks, 2017) is, here, connected to a revolutionary output bounded to transform our world in an unprecedented manner (Mathews, 2011). Said differently, the exploring attitude required by this innovation strategy is deemed capable of engendering a more respectful approach towards non-human life and environmental issues, but also to other humans. Many advocates of biomimicry have suggested that the observer's attitude it confers to designers and engineers can also ameliorate their understanding of the importance of human life, thereby leading to revolutionary effects in technological, ecological, and social spheres (Johnson, 2017).
Apart from the socio-economic sphere, the promises of research and development through biomimicry were the focus of an article by MacKinnon et al. entitled *Promises and Presuppositions of Biomimicry* (2020). Through this study, the authors intended to counter

those who defend biomimicry as inherently “good” (such as Stojanovic, 2017), whereas profit opportunities, to give an example, could lead designers and engineers to use this strategy for different purposes (Myers & Antonelli, 2012). In their paper, MacKinnon et al. highlight the promises made by practitioners of biomimicry and the high expectations created around the effectiveness of this innovation strategy in terms of sustainable change. According to the authors, “promises and expectations matter” as they offer a prospective structure that influences the agendas and actions of practitioners, policymakers, and potential investors. In other words, the types of “socio-technical imaginaries” that are linked to the concept of biomimicry “further come to shape technological development, impacting the kind of future worlds that are possible” (MacKinnon et al., 2020). This means that an indiscriminately positive view of this innovation strategy may preclude (or hinder) development directions that do not fully fit its most common definition, thereby limiting its scope and effectiveness.

2.2 Evomimetics and Climate Change

One of the criticisms levelled at the concept of biomimicry underlines the aura it gives to the powers of adaptation in natural selection. As we have seen, this concept is central to biomimetic design, as the latter aims to mimic those traits perfected over millions of years of adaptation by various living species. This has been a subject treated by Adriaens (2019) and Perricone et al. (2022), who propose an “evomimetic” and a “paleomimetic” approach, respectively, to consider the different constraints that steer the adaptation pathway towards suboptimal solutions. These notions are more precisely defined within the philosophy of biology since the well-known 1979 article by Stephen Jay Gould and Richard Lewontin revealed how common ideas on evolutionary theory prove to be erroneous or misleading. These conceptions include not taking proper account of factors other than natural selection, such as Bauplan limits, drift phenomena, niche construction, or the interdependence of organism's traits (which are often isolated in biomimicry). Thirty years later, Wilkins and Godfrey-Smith (2009) clarify how this error arises from the different “grains” in which the evolutionary process can be investigated. According to them, natural selection is a decisive element on an “intermediate grain”, lying between a focus on individual genes in a population and an overview of the different phenotypes ideally conceivable to improve the fitness of a species in its habitat. In this “most coarse-grained perspective”, many of these conceivable phenotypes have no match in actual populations, although they are often more effective than those that are actually present in nature. According to Adriaens (2019), a limitation of the common biomimetic concept is that it obstructs all these directions precisely because they are not found in the natural world.
At a time when changes in climate take place at an incomparably faster pace than in the past (Shaw & Etterson, 2012), a perspective such as the “evomimetic” one can also highlight limits in the adaptive capacity of different species. Here, the decisive element is the speed at which this process occurs, and many scientists “have expressed doubts regarding whether most natural populations will have the capacity to evolve fast enough to keep track with current climate change” (Meester et al., 2018). This aspect has already been considered in many recent agricultural innovations, which may come into play to mitigate its consequences. Several biotechnological approaches in the AgriTech sector represent an attempt to compensate for the slowness of natural adaptation in the face of abrupt climate changes (Varshney et al., 2011). Returning to the example of hi-tech beekeeping, introduced in §1, among the claimed advantages of using new technologies in this area is that of addressing honeybees’ limitations in responding to the unprecedented challenges posed by global warming (Burma, 2023; Ammar et al., 2019). The resulting environmental changes are responsible, for example, for the degradation of pollinator habitat, shifting plant flowering periods, and abrupt alterations in

weather conditions, whose effects on bee colonies can be monitored by the new IoT hives (Burma, 2023).

Despite the urgency with which this emergency needs to be tackled, the concept of biomimicry does not prove to be suitable to fit into this type of innovation in agriculture and stimulate it in new directions. Even its evomimetic re-conceptualisation is not enough because it keeps intact its approach to nature as a model (albeit limited) and to human technologies as products, without an explicit "return to nature" that may lead to hybrid results. To remedy this separation between nature and technology in biomimicry (and the one-directionality of this relationship), we will explore, in the next section, the leading contemporary philosophical currents devoted to technological innovation, particularly those relating to its analysis from an ethical perspective. We will find a possible answer from an ontologically oriented perspective that invokes the concept of the Anthropocene, which, as we will see, has also brought about a reframing of the very concept of biomimicry.

3. Responsible Innovation and Ontological Perspectives on Biomimicry

In the field of technology ethics, a perspective addressing the issue of Responsible Innovation, sometimes referred to as Responsible Research and Innovation (Stilgoe et al., 2013), has emerged in the last fifteen years, driven by substantial funding from the European Commission and the Dutch Research Council (Simon, 2016). It focuses on the challenges of detecting and addressing social and ethical issues in the early stages of technological development, incorporating public concerns into the innovation process, and fostering a reflective mindset among scientists and engineers to consider such questions (Blok, 2023). It is a task in which philosophy not only points out the moral implications regarding specific dynamics in new technologies but also provides conceptual frameworks that facilitate the integration of ethical reflections within the production apparatus. For instance, Stilgoe et al. (2013) proposed schematising innovation's "responsible" aspect into four main points: "anticipation", "reflexivity", "inclusion", and "responsiveness" (Stilgoe et al., 2013). This scheme is often used as a survey tool and evaluation metric in the context of such research (von Schomberg & Blok, 2021).

The idea of integrating moral values directly into the product design process has been developed since the 1990s by Batya Friedman (and many others) under the name "Value-Sensitive Design", with a particular focus on ICT development (Veluwenkamp & van den Hoven, 2023). Considering the different stakeholders involved in using certain technologies and their respective values is particularly important in this current of thought (Davis & Nathan, 2015). The more recent current of Design for Values has been strongly influenced by this approach, to which Ibo van de Poel (one of the leading figures in this current) has contributed by shedding light on the mechanisms suitable for translating specific values into "design requirements" (van de Poel, 2013). Emerged within the technical engineering universities of the Netherlands, Design for Values primarily attempts to guide the process of creating new technologies through guidelines that allow designers and engineers to place shared moral and social values at their centre (Veluwenkamp & van den Hoven, 2023; van de Poel, 2020). In this context, the Conceptual Engineering process addresses the analysis of values and the definition of their internal hierarchy to understand better how to integrate them into the final product (Veluwenkamp & van den Hoven, 2023). Instead, this article intends to conceptualise biomimicry differently so as not to exclude it from a path of ethical innovation. To this end, it is necessary to consider the two main perspectives in which technology has been investigated in the field of Responsible Innovation to see which one best fits our research.

3.1 Post-phenomenology

One of the leading currents of analysis connected today with the issues of technology ethics and Responsible Innovation is the postphenomenological school of thought, founded in the United States by Don Ihde and spread in the Netherlands thanks to the influence of figures such as Peter-Paul Verbeek, one of his disciples. This current intends to explore the "ontological disclosure" (Introna, 2017) provided by the different technologies, whose plural declension should be emphasised. This plurality of technologies, in fact, is intended to contrast with the Heideggerian view of Technology since, according to Don Ihde, "the elevation to technology with a capital 'T' emasculates Heidegger's philosophy of technology from making any nuanced conclusions about particular technologies (without capitals) because everything stands under the revealing power of enframed standing-reserve" (Ihde, 2010). These criticisms are a continuation of the critique, which flourished in the 1970s and 1980s, of the traditional philosophy of technology, accused of both an overly abstract approach and a pessimistic view of these issues (Bosschaert & Blok, 2022).
Moreover, this current considers technology as inseparable from the human subject since it constitutes (always in a human-technology relationship) both the subject and the object involved in the mediation (Zwier et al., 2016). In this sense, those who endorse this school of thought fall within the phenomenological tradition understood as negating a subject-object binomial placed *a priori* (Verbeek, 2015). Furthermore, they even seek to overcome the allusions to a transcendental subject in Husserlian phenomenology by drawing on the pragmatist philosophy. From the latter, Ihde emphasises the centrality of the function (or the use) of a tool for investigating this human-technical relationship. Indeed, pragmatist philosophers adopt an empirical approach in analysing technical objects from the user's point of view rather than from their existence independently from practice - which can still be found in phenomenology within its "passivity" notion (Mykhailov & Liberati, 2023) or "hyletic data" (Ritter, 2021a).
To conclude, this approach corresponded to the empirical turn in the philosophy of technology that occurred during the last decade of the 20th century (Bosschaert & Blok, 2022). Following on from this position, Verbeek (2011) develops a critique of the moral aspect of technical artefacts by identifying their "composite intentionality" (Redaelli, 2023), starting with the well-known example of obstetric ultrasound, which he compares with those of New York overpasses in Langdon Winner (1980) and speed bumps in Bruno Latour (1999). His work, recognised even outside the Dutch universities where he teaches, can be understood as a deepening of the post-phenomenological enquiry into the ethics of technology and an opening towards applying its abstract principles in the context of technical design and engineering.

3.2 Ontological Turn and Anthropocene

While postphenomenology promises to reveal the profound influences operated by technology on human experience, critics of this approach complain about "insensitivity to broader contexts, for instance, the social or political contexts, of human being with technology" (Ritter, 2021a). According to Ritter's analysis, this is the meeting point of the two main criticisms levelled against the school of thought founded by Ihde, namely the "existentialist" criticism advocated by Robert C. Scharff, and the "ontological" criticism by Jochem Zwier, Pieter Lemmens and Vincent Blok (Ritter, 2021b), which we will analyse later. These philosophers also object to the empirical turn of the philosophical studies on technology for rejecting the traditional philosophy on this subject, considering it legitimate to rehabilitate past non-empirical approaches as a framework for analysing concrete situations (Bosschaert & Blok, 2022). These include Vincent Blok, professor at Wageningen University & Research, who, as we have seen, is also a central figure in the philosophical debate on biomimetic technologies.

He agrees with postphenomenology on the need for philosophy and ethics of technology to contain a dose of empirical material, “for, as philosophers, we need to know the object of our studies” (Bosschaert & Blok, 2022). However, in the same article just cited, the two authors criticise the self-evidence of the concept of “empirical” approach, which has been declined in very different directions in the three main branches of the philosophy of technology that have adopted it since the 1990s: postphenomenology, the critical theory of technology, and the analytic philosophy of technology. Furthermore, Blok disagrees with a view of technology that considers it exclusively from this perspective and ignores the impact of widespread technological innovations, e.g., those related to the digital revolution, on the conception of our being in the world (Blok, 2023). In his opinion, it is the very meaning of “innovation” that allows and invites an “ontological turn” in philosophical studies on technology, while not denying the ontic aspects of innovation outcomes and processes. As delineated in his articles concerning the foundation of a philosophy of innovation, this concept is only revealed in its specificity on an “ontic-ontological dimension” (Blok, 2021). That means taking into account new technologies’ ontological impact not only inasmuch as it occurs through their possible use (as in the case of Verbeek’s obstetrical ultrasound) but also considering how they condition our reality even outside our direct experience of them through their diffusion throughout the world. It is in the attempt to define this point that Blok has recently proposed a methodology called “Material Hermeneutic Phenomenology”, which rehabilitates the “content sense” of the phenomenon beyond the Husserlian *epoché* and thus allows the ontological to be linked to the ontic even outside the experiential ladder analysed by postphenomenology (Blok, *forthcoming*).

It should be emphasised that the rehabilitation of an ontological dimension in the philosophy of technology is also linked to the popularisation of the concept of the Anthropocene. It is a view shared by some philosophers of Responsible Innovation that the Anthropocene condition requires a more comprehensive and “whole-oriented” philosophical approach to technology than the empirical one, without substituting the latter but rather complementing it through a macroscopic perspective (Lemmens et al., 2017). Indeed, this planetary condition calls for “redirecting our attention from the micro-level to the macro-level and from the empirical to the transcendental again” (Lemmens, 2022). These thinkers advocate a “terrestrial turn” in the philosophy of technology, capable of considering this field beyond not only individual artefacts but also the “broad socio-cultural phenomenon that traditional philosophers of technology like Marcuse, Jaspers and Ellul saw in it”. Instead, we should be able to theorise technology as a “planetary phenomenon in its own right” (Lemmens, 2022). The Anthropocene experience, made concrete by global warming, is described by Blok as a phenomenon that is not only ontic (as a scientifically determinable geological event) but also, above all, ontological (Blok, 2022b). Indeed, it entails disrupting the way reality is perceived as a whole and how human beings respond to it. By “ontology”, he does not refer to eternal metaphysical concepts but to temporally determined categories with which the meaning of being in the world is established in a given epoch, influencing subsequent developments (Blok, 2022b).

At the same time, in light of the conception that the Anthropocene gives us of technology, he also questions the actuality of Heidegger’s view that the essence of technology has nothing technological about it (Heidegger, 1970). The Anthropocene concept and the experience of global warming, in fact, originated from technological innovations that can be ontically determined in their invention and diffusion, both of which had repercussions on an ontological and global scale. In this geological epoch, “technology at an ontic level seems to disrupt the world at the ontological level,” just as the invention of the steam engine had made natural and human resources appear in their mobility and non-locality, thereby founding the world itself as ontologically pattered as a “converted convertor” (Blok, 2022b). It is thus evident how the

Anthropocene condition highlights the ontic-ontological nature of innovation that we mentioned above and, therefore, requires a two-pronged approach.

3.3 The eco-centric concept of biomimicry

In Vincent Blok's article entitled *Earthing Technology: Toward an Eco-centric Concept of Biomimetic Technologies in the Anthropocene* (2017), we find a perspective on biomimicry that proposes itself as a guiding light for its future developments. The point of view here exposed underlines the aspects that emerge once one compares this practice with the current conception of the Anthropocene, investigated from a Spinozian perspective. In the first place, an Anthropocene-oriented viewpoint stresses the embeddedness of biomimetic technologies in our ecosystem, which is already present in the writings of Benyus (2002), and reinforces its ethical implication (Blok & Gremmen, 2016). Starting from Crutzen and Schwägerl's (2011) assertion that, in this epoch, "nature is us" (italics in the text), Blok reformulates it in terms of an "ontic-ontological experience of the whole of being in which human existence is included, i.e., the experience that we live on Earth and as Earth" (Blok, 2017). At the same time, Earth's dynamics prove to be less and less controllable and increasingly unstable and volatile. From this point of view, he criticises the anthropocentric orientation of the traditional formulation of biomimicry, which can be found in much of its literature. For example, according to Blok, this is visible in the concept of "emulation" employed by Benyus, which presupposes "not only imitation but also competition with nature" (Blok, 2017). He, therefore, proposes an "eco-centric concept of biomimicry" that also takes into account the "wider ecological context in which these hybrids emerge and fade away, ranging from the eco-systems in which they are embedded to the dynamic systems on which they depend at both the ontological and the epistemological level" (Blok, 2017).

This "eco-centric" formulation should not be confused with the one developed in a later article by Blok and Gremmen (2018), where they advocate a design of Smart Farming Technologies that mimics a closed-loop ecosystem. By reconceptualising these technologies for agriculture, another type of biomimicry is proposed, here defined as the imitation of the ecosystem rather than individual traits of natural organisms. In contrast, from an eco-centric perspective on biomimetics emerges an openness of this concept towards a hybridisation of technology and nature (forming "natural-technological hybrids", as in Blok, 2017) within the horizon of a common belonging to the Earth system. In the 2017 paper, therefore, the "ecosystem" is thus conceived within an integrated vision of technologies and nature on a global scale and not as another model from which to derive closed systems in agriculture, however hybrid they may result.

4. Eco-centric evomimetics and AI in agriculture

In this section, we will attempt to combine the evomimetic and eco-centric conceptualisations of biomimicry. We propose that the eco-centric perspective can implement the evomimetic one, *per se* still centred on imitating the physiological traits of natural species, in revealing the possibility of creating natural-technological hybrids against the backdrop of the Anthropocene. Conversely, the evomimetic perspective adds an evolutionary dimension to these hybrids, suggesting that their development should be seen as an aid to other organisms or populations in their adaptation to the rapidly changing environmental conditions. Together, these two directions open the concept of biomimicry to the modification of natural traits relative to species from which, *a priori*, it only took inspiration. By preserving its imitative method, an "eco-centric evomimetic" biomimicry can engender a sort of phenotypic "recombination" among species beyond the limits of natural adaptation.

Without delving into the possibilities offered by genetic engineering and the associated ethical considerations, an example of interest may be the integration of artificial intelligence (AI) in agriculture, particularly in beekeeping. As far as the meaning of Artificial Intelligence is concerned, whatever definition is given to it, "the core concept of AI has continuously been to create machines that were capable of thinking like humans" (Goralski, 2020). Ryan (2020) describes this technology as "artificial mimicry of tasks and functions that would otherwise require human intelligence". Moving on to its use in agriculture, literature devoted to the impact of the so-called "digital revolution" in beekeeping focuses on the use of AI in correlation with sensors and cameras to provide the beekeeper with more robust predictive data or a more informed overview of bee colony health (see, for example, Burma, 2023 and Grammalidi et al., 2023). As Ryan (2022) points out, however, in addition to "AI software" products, which process large amounts of data to aid the farmer's decision-making, there are now also "AI robots" that "work (relatively) autonomously on a farm", for instance in harvesting fruit or spraying pesticides on fields. Therefore, other directions of using this technology in beekeeping are now envisaged, in partial independence of the beekeeper's activity. Indeed, recent research foresees the use of AI in producing robotic hives that function with a certain degree of autonomy, adapting themselves to the activity of the swarm (Romano, 2023). As an example, since 2016, the European Union has been funding the so-called "HIVEOPOLIS" project, which consists of building "an autonomously running bio-hybrid" system by embedding these technologies in beehives so as to improve the living conditions of the colony in the context of new environmental challenges (Ilgün et al., 2021). In this way, just as we draw inspiration from the internal organisation of the swarm (the "swarm intelligence") to achieve a biomimetic design of the interaction between "Cloud Robots" (as in Gkiokas et al., 2015), biomimicry can also follow the opposite direction, applying the technological imitation of human intelligence (AI) to bee colonies by producing hives that run autonomously.

5. Conclusion

The threads of this article began by describing the various meanings of biomimetic design and highlighting the risks of considering it as endowed with an intrinsic morality due to its "natural" connotation. In doing so, as we saw, there is a danger of not paying attention to this innovation strategy's limitations and not interrogating it from different angles to understand its full potential better. A conceptual engineering of it can indeed steer this practice in new directions of ethical innovation, adapting the concept to new morally significant needs or specific technological fields. We have then analysed the "evomimetic" critique of biomimicry, which suggests considering the limits of natural selection. Despite what pro-biomimicry literature says, these constraints lead a species towards suboptimal solutions to the challenges imposed by its environment. Hence, we have noted how this perspective may also point to the limits of natural selection in keeping up with abrupt changes in climate resulting from human-induced global warming. Some R&D directions in technological agriculture are trying to solve this problem by adapting new technologies to domesticated species. Although it may suggest interesting new perspectives in this area, neither the common understanding of biomimicry, nor the evomimetic critique alone, prove suitable for applying the biomimetic innovation strategy to this line of development. As we have argued, it would be necessary to overturn the idea that nature is the model and the Umwelt of human life the target of biomimicry, and to include humanity in the model and nature in the target by blurring their boundaries.

We have therefore reviewed the main branches of the philosophical study of technology in the field of Responsible Innovation, to find in the (re)emergence of an ontological perspective a consonance with the Anthropocene discourse, with its hybridisation of humanity and nature from the standpoint of climate change awareness. Vincent Blok, one of the main proponents of

this line of thought, formulated an "eco-centric" outlook for biomimetic design that we argued could complement the evomimetic critique in directing biomimicry into the integration of new technologies in agriculture by "evolving" domesticated species into (semi)autonomous natural-technological hybrids. In particular, this would pave the way for a biomimetic understanding of the incorporation of human-inspired Artificial Intelligence into natural organisms or systems, as in the cases of AI robots applied to beehives, on which our examples focus.
To conclude, we hope that this analysis of biomimicry combining the eco-centric and evomimetic viewpoints will lead to further studies on how to apply this conceptual reframing within research and development laboratories to facilitate the design of new technologies for ethical innovation in this field.

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