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Technology as *Mimesis:* Biomimicry as Regenerative Sustainable Design, Engineering, and Technology

Vincent Blok

Abstract: In this article, we investigate how to explain the difference between traditional design, engineering, and technology—which have *exploited* nature and put increasing pressure on Earth's carrying capacity since the industrial revolution—and biomimetic design—which claims to *explore* nature's sustainable solutions and promises to be regenerative by design. We reflect on the concept of *mimesis*. Mimesis assumes a continuity between the natural environment as a regenerative *model* and *measure* for sustainable design that is *imitated* and *reproduced* in biomimetic design, engineering, and technology. We conceptualize *mimesis* in terms of two interdependent boundary conditions: differentiation and participation. We subsequently develop four characteristics of biomimicry as regenerative design, engineering, and technology: technological *mimesis* is 1) a participative differentiation of nature; 2) supplemental to natural *mimesis* in biomimetic design; 3) the participative differentiation of technological *mimesis* is constitutive of nature; 4) the participative differentiation of technological *mimesis* is always limited.

Key words: Biomimicry, design, ethics of technology, regenerative development, technology

1. Introduction

In present-day society, the exploitation of nature is so disruptive that the future of human existence on planet Earth is threatened. In order to ensure the sustainability of Earth's life-support systems for human life on Earth, a concept of sustainability is required that integrates the triple bottom line of *People*, *Planet*, *Profit* in our production and consumption processes. This trend is supported by innovations

Vincent Blok, Associate Professor, Philosophy Group, Wageningen University, Hollandseweg 1, 6707 KN Wageningen, The Netherlands; info@vincentblok.nl

in design, engineering, and technology that enable the reduction of waste and the improvement of resource efficiency in the development of a circular biobased economy. In this context, biomimetic design, engineering, and technology is considered a promising way forward (Blok 2017).

Biomimicry or biomimetics refers to the "philosophy and interdisciplinary design approaches taking nature as a model to meet the challenges of sustainable development (social, environmental, and economic)" (BSI 2015). Biomimetic technologies imitate natural design—e.g., a termite mound—to solve technical problems—e.g., temperature regulation in the built environment. As the natural environment provides sustainable solutions—e.g., nature recycles everything, nature is locally attuned and responsive, nature banks on diversity, and so on (Baumeister et al. 2013)—biomimetic technologies provide, creative solutions that prove effective in nature. Importantly, the more these biomimetic technologies are embedded in and mutually benefit both the design and the natural ecosystems of planet Earth, the more they can claim to be sustainable technologies, i.e., reduce negative environmental impacts and contribute to regenerative development (Hayes, Desha, and Baumeister 2020). Regenerative design can be defined as design that prevents the *destruction* of the Earth's ecosystems while actively renewing and progressively reconstructing them.

According to Peter Sloterdijk, traditional technologies are based on principles that are heterogeneous to natural design. They can be associated with the domination and *exploitation* of nature (Sloterdijk 2011). Contrary to these heterogeneous technologies that have put increasing pressure on Earth's carrying capacity since the industrial revolution (Sloterdijk and Heinrichs 2006), biomimetic or *homeo*-technologies are based on principles homogeneous to natural design. They can be associated with learning and the *exploration* of nature's sustainable solutions. Proponents like Janine Benyus (2002) claim that biomimetic technologies could potentially underpin a new industrial revolution, because they no longer exploit nature. Instead, they learn from nature and could pave the way for a genuine approach to regenerative sustainable design, engineering, and technology.

This raises the question of how exactly to explain the difference between the two types of technology, and whether this difference can in fact account for high ecological performance of biomimetic technologies in contrast to traditional technologies. Is it really the case that traditional designers aim to exploit the Earth while biomimetic designers opt to explore nature? It seems logical to point to the *mimetic* nature of biomimetic technologies, which assumes a continuity between nature and technology, i.e., a continuity between the natural environment as a re-

generative *model* and *measure* (Baumeister et al. 2013) for sustainable design, and new technologies that *imitate* and *reproduce* this model and measure and can then also claim to be a regenerative sustainable design.

Closer inspection, however, reveals all kinds of difficulties with the notion of *mimesis*. 1) If biomimetic technologies are real imitations of nature, why should we invest in technology when we could also 'grow' the natural design? In other words, what would the added value of biomimetic technology be if nature itself could do the job? 2) At a conceptual level, biomimicry may claim to be regenerative, but, in practice, most biomimetic technologies focus on efficiency and optimization and not on sustainable performance, even if most cases of biomimetic design provide opportunities to reduce waste, improve efficiency in resource use, and so on (Hayes, Desha, and Baumeister 2020). In other words, *mimesis* may be a necessary condition for regenerative design, but is not yet a sufficient condition. 3) Biomimicry does not simply imitate nature in technological design, because our technological problems pre-structure the way we see and understand nature (Bensaud-Vincent 2011). It is only because we have a problem with energy intensive air conditioning systems that a termite mound appears *as* a natural air conditioning system. Furthermore, biomimicry practitioners argue that a direct imitation of a biological prototype in a technological design is rarely successful and requires a translation from biology to technology (Vincent et al. 2006). Can we claim to mimic nature if technological problems pre-structure our understanding of the natural environment and require translation? 4) Earth system sciences show that the natural environment is unstable and volatile (Clark 2011). What are the consequences of the instability of the natural environment for the desirability of technologies that mimic nature?

These difficulties with the theory and practice of *mimesis* in biomimetic design, engineering, and technology show that the continuity between the natural environment as a regenerative model and technological design can be questioned, and, with this, the sustainability claims involved. Biomimicry cannot consist in a simple imitation and reproduction of nature's model in technological design but requires translation and management. For this reason, authors like Peter Forbes reject the name biomimicry, as it involves a "slavish copying of Nature" (Forbes 2005, 18–19). Instead, they argue for bio-inspiration, highlighting the newness of technological design beyond natural design (Forbes 2005, 18–19). But if technological design is only inspired by nature and mimics only selected features of an organism—e.g., a wasp sting that inspires a self-propelling Ovipositor Device for surgery—the difference between the two types of technology—e.g., the claim that

biomimicry could pave the way for a genuinely approach to regenerative sustainable design—becomes questionable.

If we define biomimicry as *mimesis* of nature in the literal sense of the word, then we understand how nature can function as a model for regenerative technological design and how this model can account for the difference between the two types of technology. In reality, nothing corresponds with this idea. If, however, we define biomimicry more loosely as bio-inspiration, then almost all technologies can count as bio-inspired—genetic modification of plants and animals can be seen as inspired by the natural way in which DNA duplicates over generations—and it is no longer clear how these bio-inspired technologies are differentiated from traditional technological exploitations of nature.

How can we define mimicry and *mimesis* to differentiate between both simple imitation and mere inspiration for inventions and guide regenerative sustainable design? In answering this question, we cannot expect help from material scientists, engineers, and designers working in the field of biomimicry. They often engage in actual new product development without considering its conceptuality, or their potential contribution to sustainable development (Hayes, Desha, and Baumeister 2020). In this article, we reflect *philosophically* on the nature of *mimesis* in biomimetic design, engineering, and technology, building on the emerging field of the philosophy of biomimicry (Dicks 2016; Blok and Gremmen 2016). Philosophy questions dominant conceptualizations, clarifies conceptual ambiguities, and engages in conceptual engineering to advance theory and practice in the interdisciplinary field of biomimicry.

In §2, we set the stage by discussing how *mimesis* is conceptualized in the philosophical tradition. We show that the concept cannot be understood with reference to classical categories like imitation and invention, but rather concerns a completely new category. We conceptualize this new category in terms of the supplementarity of *mimesis*. We define the supplementarity of *mimesis* in terms of two interdependent boundary conditions: differentiation and participation. In §3, we apply this concept in the context of technological *mimesis* to characterize biomimicry as regenerative sustainable design. We develop four characteristics of technological *mimesis* as design, engineering, and technology. We draw conclusions in §4.

2. The Opportunities of *Mimesis* as Regenerative Design, Engineering, and Technology

In order to assess the opportunities and limitations of biomimicry as an imitation of the model of nature, we consult the philosophical tradition. The idea of biomimicry as an imitation of nature can be traced in Plato's work, for whom *mimesis* can mean a variety of things: representation, copy, reproduction, expression, and so on. Although Plato is famous for his rejection of art because of its *mimetic* nature, it is good to consider that he does not reject *mimesis* as such, like he does not reject art as such (Blok 2020). He only rejects the *mimesis* of art in light of his concept of truth as *homoiosis* (likeness, resemblance, correctness). Plato's famous condemnation of art consists in the fact that the artistic *mimesis* attempts to *mimic* the real tree in a painted tree for instance, but it does not succeed in this effort. This is why Plato condemns artistic *mimesis*: its effort to copy nature as a representation of the original model always leads to degeneration, i.e., to a deficient imitation of perfect nature. Whereas the ideal of *mimesis* is to imitate nature, its reality consists in degeneration with respect to the original. In this regard, we might argue that some of the issues that we have raised regarding *mimesis,* just like its condemnation as a slavish copy of nature by people like Forbes (see §1), can be traced in the philosophical tradition.

We can contrast the negative assessment of *mimesis* in Plato's case with a more positive conceptualization in the case of his apprentice Aristotle. According to Aristotle, art and technology *imitate* (*mimeitai—mimesis*), accomplish, or perfect what nature is not capable of effectuating itself (Aristotle 1980, 199a20–25).

> Now, when a thing is produced by Nature, the earlier stages in every case lead up to the final development in the same way as in the operation of art, and *vice versa,* provided that no impediment balks the process. The operation is directed by a purpose; we may, therefore, infer that the natural process was guided by a purpose to the end that is realized. Thus, if a house were a natural product, the process would pass through the same stages that it in fact passes through when it is produced by art; and if natural products could also be produced by art, they would move along the same line that the natural process actually takes. (Aristotle 1980, 199a8–20)

According to Aristotle, the technological construction of a house mimics natural principles and processes. This does not mean that the house itself is an equivalent of nature. It means that if nature were able to build a house, it would follow the same building processes and stages as our technological constructions.[1] For Aris-

totle, the imitation of nature is possible. We call this conceptualization of mimicry the imitation of the naturally given.[2]

This naturalistic account of mimicry can be found in various biomimetic practices that imitate natural forms or processes (Hayes, Desha, and Baumeister 2020). The naturalism of this conceptualization of *mimesis* consists in the imitation of the physical shape of natural phenomena in technological design, e.g., mimicking the kingfisher bird in the design of the nose cone of the Japanese bullet train to reduce the air friction caused by trains moving into and out of tunnels. The imitation can also concern natural processes. For instance, imitating organic growth and healing processes in the development of self-healing and self-repairing concrete.

Besides imitating nature, *mimesis* can progressively supplement the capacity of nature, according to Aristotle—particularly, in cases where *mimesis* accomplishes and perfects what nature is not capable of effectuating itself. We call this the supplementary nature of *mimesis*: when something is added to the original in order to complete or perfect nature. What is it that nature cannot effectuate itself according to Aristotle? Nature provides access to all kinds of sensory phenomena that we encounter in the world; however, it does not extend to general patterns or universals that constitute concepts like 'tree,' 'man,' and so on. The mimetic perfection of nature articulates such general patterns or universals like 'tree' and 'man.' Aristotle provides examples of the perfection of nature within artwork: Art, such as poems or paintings, are capable of conveying general patterns of human life—e.g., the tragic nature of human life—that cannot be observed directly through the use of poetic fiction (Aristotle, 1995: 1448a1–5). This fiction is not inductively derived from natural phenomena, but rather the product of a mimetic act that actively constitutes a type or category that subsumes individual humans under a generic term (Dicks 2017). At the same time, this mimetic act is not a free invention because it re-enacts what is already there in natural phenomena, albeit in an underarticulated manner. The mimetic perfection of nature consists in the articulation of general patterns, types, or categories *in* these natural phenomena. We call this the poetic concept of mimicry as perfection of the naturally given.

This poetic account of mimicry can be found in biomimetic practices at system level that mimic general patterns and principles adopted in ecosystems (Hayes, Desha, and Baumeister 2020; Marshall and Lozeva 2009). Benyus, for instance, identifies several life principles like 'nature runs on sunlight' or 'nature recycles everything' that can guide technological design. These principles are not inductively derived from natural phenomena. Rather, they are the product of a mimetic act that constitutes life principles like 'nature runs on sunlight.' While the

naturalistic account of mimicry indicates the biomimetic imitation of a naturally given form or process—e.g., the symbolic imitation of the form of the gecko's toes or the imitation of wound-healing processes—the poetic account of mimicry indicates the biomimetic articulation of life principles that govern ecosystems like 'nature demands local expertise' or 'nature uses only the energy it needs' in technological design (Benyus 2002).

Contrary to Plato, Aristotle's conceptualization of *mimesis* is positively framed as perfection with respect to the original. In fact, we see a reversal between Plato's and Aristotle's appreciation of *mimesis* to the extent that art and technology are no longer seen as degenerative with respect to perfect nature as the original. Instead, nature is deficient because it cannot accomplish or effectuate everything and needs art and technology to become perfect.

To what extent does Aristotle's conceptualization of *mimesis* help us to understand and eventually solve the issues with *mimesis* mentioned in the introduction to this article? The first issue encountered was that it is not clear why we should invest in technology if biomimetic technologies are seen as real imitations of nature. Why should we invest in technology when we could also 'grow' the natural design? According to Aristotle, nature and technology are essentially the same as we have seen, meaning that natural growth follows the same principles as artificial construction. The only difference between the two is that the starting point for the operation of these principles in natural design is found internally (the development of natural entities is determined from within themselves). In the case of technological design, it is found externally in the human designer. A house does not grow naturally; we do not grow a house; we invest in its construction.

But if *mimesis* supplements the capacity of nature according to Aristotle, how can we distinguish between a mimetic supplement of nature and a nature-inspired invention of something completely new? Given that we are interested in a concept of *mimesis* beyond simple imitation and mere inspiration, we now ask how the supplementary nature of the poetic account of *mimesis* has to be understood.

Philosophically, the supplementarity of *mimesis* involves a twofold principle: A as original and A^1 as supplement of the original that cannot be lifted by any *mimesis*. Why? '*Sup-*' means to add from the bottom up, so an addition (A^1) to the original (A). This addition cannot be identical with the original. Otherwise, a sup-plement of the original would be neither possible nor necessary.[3] In other words, the supplementarity of *mimesis* shows that biomimicry always involves a twofold between natural design and technological design that cannot be bridged. *Mimesis* always involves change ($A \rightarrow A^1$), and change explains why practitioners

find that the direct imitation of a biological prototype in technological design is rarely successful and requires interpretation, translation, and management. If *mimesis* always involves change ($A \rightarrow A^1$), it is better understood as a *variant* of the original.[4]

But if the *mimesis* of the natural original (A) always involves change (A^1), how can we distinguish between change as a mimetic variant of A (A^1) and change as a nature-inspired invention of something completely new (B)? Our poetic account of *mimesis* might help us here: The mimetic variant of A differentiates a general pattern (principle, type, or category) from the original—natural phenomena—but remains embedded in and participates with this original, which it perfects.[5] This embeddedness and participation in natural phenomena can help to distinguish *mimesis* and invention because a mimetic variant differentiates from the original but remains embedded in and participates with this original—it adds something *to* the original,[6] whereas, the invention of something completely new consists in a differentiation without such remaining embeddedness.[7] The poetic account of *mimesis* as a supplementary variant of the original is dependent on the naturalistic account of *mimesis* as an imitation of the original at form, process, or system level, as it limits this mimetic variant to those differentiations that remain embedded, and participate, in the original. If then, and only then, is it a variant and not something invented completely anew. At the same time, we can argue that the naturalistic account of *mimesis* as an imitation of the original is dependent on the poetic account. If the *mimesis* of the natural original (A) involves the constitution of a supplement (A^1), then the poetic account limits the mimetic variant to those differentiations that move beyond a slavish copy of nature. However, this proves difficult, if not impossible, in practice.

By consulting the philosophical tradition, we can now properly conceptualize *mimesis*. We move beyond Aristotle's narrow interpretation of *mimesis* as imitation and perfection. We reconceptualize them as two boundary conditions that constitute the supplementarity of *mimesis:* differentiation and participation. This conceptualization of *mimesis* enables us to differentiate between biomimicry ($A \rightarrow A^1$) and strict imitation of nature (A=A) on the one hand and nature-inspired invention ($A \rightarrow B$) on the other. With this, it becomes clear that *mimesis* cannot be conceptualized with the help of common categories like imitation and invention but introduces a new category.

If we apply the conceptualization of *mimesis* that we have developed so far to biomimetic design, engineering, and technology, we can define biomimicry as differentiation of a technological design *beyond* Earth's biosphere or ecosystems

that at the same time remains embedded, and participates, in these ecosystems. Such a definition holds that biomimetic technologies mimic life's principles, such as 'nature rewards cooperation' or 'nature uses only the energy it needs' (Benyus 2002), in technological design. Due to their mimetic nature, biomimetic design, engineering, and technology take Earth's ecosystems as their point of departure in the development of new technological design and are at the same time responsive to the wider ecological context on which these technologies depend (Blok 2017).

With this, we also provide a criterion to distinguish between traditional, *exploitative* technologies and biomimetic, *exploratory* technologies that can claim to be regenerative based on their mimetic nature. Many technologies that mimic natural forms or processes cannot claim to be sustainable solutions, even if they provide opportunities to reduce waste, improve efficiency in resource use, and so on. Regenerative design not only requires us to mimic natural forms and processes, but should also be responsive to these natural ecosystems by renewing and reconstructing them, and by being responsive to these ecosystems (Marshall and Lozeva 2009). Our concept of *mimesis*—as differentiation of a technological design *beyond* Earth's biosphere or ecosystems, which at the same time remains embedded in and participates with these ecosystems—operationalizes this necessary and sufficient condition for biomimicry as regenerative design. This conceptualization of *mimesis* in biomimicry helps us to criticize efforts both to imitate particular features or mechanisms of organisms and to invent features or mechanisms that are inspired by nature but are not embedded in Earth's ecosystems. At the same time, this conceptualization of *mimesis* helps us to operationalize biomimicry as regenerative sustainable design.

3. The Limitations of *Mimesis* as Regenerative Design, Engineering, and Technology

The second issue raised in the introduction with regard to *mimesis* was that earth system sciences show that the natural environment is unstable and volatile (Clark 2011). This raises questions regarding the limitations of biomimetic technological design. The instability and volatility of the natural environment is differently conceptualized in various disciplines. For instance, in philosophy it is conceptualized as *steresis.* According to Aristotle, the withdrawal of nature belongs to its self-emergence. In biology, it is conceptualized in terms of a *terra incognita*; many varieties of microbes, plants, and animals are still unknown to us. In bio-inspired design practice, it is experienced in practice, as most of the original functions and mechanisms of natural design are unknown to the designer. No matter how

this instability is conceptualized, the question is raised of how to *embed* biomimetic design in the ecosystems of planet Earth if these ecosystems withdraw at an epistemic level. In this section, we first return to the concept of *mimesis* to conceptualize nature as *terra incognita* that is mimicked in technological design. Subsequently, we sketch the consequences of nature as *terra incognita* for our concept of biomimicry as regenerative design, engineering, and technology.

Building on Aristotle's work, Jacques Derrida pointed out that technological *mimesis* remains embedded in a natural *mimesis*:

> At the beginning of the *Poetics mimesis* in a way is posited as a possibility proper to *physis. Physis* is revealed in *mimesis,* or in the poetry which is a species of *mimesis*, by virtue of the hardly apparent structure which constrains *mimesis* from carrying to the exterior the fold of its redoubling. It belongs to *physis*, or, if you will, *physis* includes its own exteriority and its double. In this sense, *mimesis* is therefore a 'natural' movement. (Derrida 1982, 237)

Here, *mimesis* is seen as a natural movement because the ability to mimic is embedded in the *nature* of human being. Nature, itself, allows the possibility of its *mimesis* by technology. It is also a doubling movement because mimicry necessarily doubles nature in technological design. In this sense, the supplementarity of technology is natural in two senses of the word according to Derrida: allowed by nature and doubling nature.

But we can go a step further: If nature and technology are essentially the same (as Aristotle argued [1980, 199a10–20]) and the essence of technology is found in a *mimesis* of nature, then technological *mimesis* may be rooted in, and derived from, an original *natural mimesis*. Nature allows for technological *mimesis* as a doubling variant of nature—i.e., nature as the appearance of natural forms, processes, and ecosystems that can be mimicked in technological design. Nature is not mere appearance, but primarily an unpredictable, indeterminable, and unfathomable elementary sphere (Blok 2019) from which a variety of natural entities emerge in the evolutionary process of trial and error of new variants that can turn out to be the fittest to survive or not. *Mimesis* then concerns the ontogenetic process in which a new supplementary variety emerges and shows itself as such a variety of its predecessor (Blok 2016a). *Mimesis* primarily *shows* something. Natural *mimesis* then shows a *natural* supplement that remains embedded, and participates, in this ontogenetic process of nature that is itself indeterminable and unfathomable, i.e., that remains a *terra incognita* as a background condition for

each and every mimetic variety in the foreground. It is the natural supplement—a gecko foot, a healing wound, a natural ecosystem like a forest—that is mimicked in a technological supplement, not the elementary nature out of which these supplements emerge.[8]

The concept of *mimesis* enables us to understand nature as *terra incognita* in terms of the supplementary nature of natural *mimesis.* Natural *mimesis* involves a distinction between nature as mimetic variety that can be mimicked in technological design, and nature as *terra incognita*, which is the origin of any natural *mimesis*. Nature as *terra incognita* cannot be mimicked in technological design because it is unfathomable and unpredictable at an ontological and epistemological level (Blok 2019). However, any natural *mimesis* remains embedded in nature and supplements it when acting as *terra incognita*. The duality of nature involved in the supplementarity of natural *mimesis* explains, on the one hand, why the evolutionary process of new variant emergence will never end in a static form, process, or ecosystem but will always adapt under pressure from internal and external factors and which constitute Earth's dynamic ecosystems. This means, on the other hand, that the technological *mimesis* embedded in Earth's ecosystems has to be understood as an integral part of these dynamic ecosystems.

If we consider differentiation and participation as a first characteristic of the supplementary nature of *mimesis* that can inform a regenerative concept of biomimetic design, engineering, and technology, then a second characteristic is revealed: a regenerative concept of technological *mimesis* that remains embedded in natural *mimesis.* All technological *mimesis* remains embedded in natural *mimesis* as an ontogenetic process in which natural forms, processes, and ecosystems emerge but also remain embedded in unfathomable and unpredictable nature as *terra incognita.*

The duality inherent to the concept of natural *mimesis* between the natural forms, processes, and ecosystems as the mimetic outcome of the ontogenetic process, and nature as the origin of these supplementary forms and processes, opens a new perspective on *mimesis* as the perfection of nature encountered in the previous section. One can argue that the conceptual duality of natural *mimesis* enables us to reject the idea of technology as the *perfection* of nature. Nature does not have to be associated with a lack or a flaw that can be remedied by human technological design. It withdraws itself at an epistemic and ontological level in the process of natural and technological *mimesis.* Natural and technological *mimesis* do not perfect the imperfect; rather, natural *mimesis* constitutes natural forms, processes, and

ecosystems for the first time. Without such a constitutive *mimesis*, nature would remain a *terra incognita*.

This constitutive role of *mimesis* is confirmed by one of the most important philosophers of *mimesis*: Philippe Lacoue-Labarthe. According to Lacoue-Labarthe, there is no fixed, real original that can subsequently be mimicked in *mimesis*, as classical philosophers of *mimesis* like Aristotle assumed. The original is only accessible via *mimesis;* therefore, it is only a supplement of this original. The original supplementarity of *mimesis* means that the original is only given *in* the supplementarity of *mimesis.* According to Lacoue-Labarthe, this original supplementarity is at stake in all our relations with the world:

> In reality, we have to wrest mimetism away from the classical conceptions of *imitation* and rethink it in the light of a rigorous mimetology. The structure of original supplementarity is the very structure or the relation between *techné* and *physis*. (Lacoue-Labarthe 1990, 83)

Although this idea may be counterintuitive, it is confirmed and substantiated by our notion of nature as *terra incognita*. In which, the origin of natural *mimesis* embeds natural forms and processes. Because nature as *terra incognita* is inaccessible at an epistemological and ontological level, it is only via a mimetic supplement that we have access to this origin. In this respect, *mimesis* is not a re-presentation or re-production of the original. Instead, mimesis *constitutes* this original for the first time. This is what Lacoue-Labarthe calls the original supplementarity of *mimesis* (Lacoue-Labarthe 1989, 1990; Peperstraten 2005).

The constitutive nature of the supplementarity of *mimesis* holds that the relation between the natural forms, processes, and ecosystems constituents the mimetic process, and nature is the origin of these supplementary forms and processes. Further, it holds that the relation between the natural forms and processes are supplemented by technological design. Technological *mimesis* brings something new to natural *mimesis*, a supplement, and only this technological supplement provides access to the natural forms, processes, and ecosystems as the origin of technological *mimesis*, just like a natural supplement provides access to nature as origin of these supplementary natural forms and processes of natural *mimesis.*

With this, we encounter a third characteristic of the supplementary nature of *mimesis* that can inform a regenerative sustainable concept of biomimetic design, engineering, and technology: the constitutive nature of the supplementarity of natural and technological *mimesis.* The constitutive nature of the supplementarity of *mimesis* enables us also to address the third issue raised in the introduction

regarding the nature of *mimesis*: biomimicry does not simply imitate nature in technological design because our technological problems pre-structure the way in which we see and understand nature (Bensaud-Vincent 2011). On the one hand, technological *mimesis* is not inductively derived from nature but rather the product of a mimetic act that constitutes a general pattern or principle, as we have seen. On the other hand, it is only because we have a problem with energy, for instance, that makes 'nature runs on sunlight' appear as a potential solution. We can even broaden the argument and argue that these principles of nature can only appear as a natural model and measure for technological *mimesis* after technological mediations (laboratories, microscopes, and so on) reveal this principle as a principle of nature. The constitutive nature of the supplementarity of *mimesis* confirms that mimetic technology pre-structures the way in which we understand nature. At the same time, our conceptualization of *mimesis* can address the issue that technology pre-structures nature *before* it is mimicked. On the one hand, the constitutive nature of technological *mimesis* holds both for natural and technological *mimesis.* On the other hand, the constitutive nature of technological *mimesis* is not problematic as long as it is accompanied with the first characteristic of *mimesis* that we have introduced, as it guarantees that the constitutive nature of technological *mimesis* remains embedded, and participates, in Earth's ecosystems.

The duality in the concept of natural *mimesis* between natural forms, processes, and ecosystems as mimetic outcome of the ontogenetic process, and nature as origin of these supplementary forms and processes, opens a new perspective on the deficiency of nature encountered in the previous section. One can argue that the duality of the concept of natural *mimesis* enables us to reject the idea of a deficiency of nature: nature does not have to be associated with a lack or a flaw that can be remedied by human technological design. Nature can also be understood in terms of an abundance that gives rise to multiple possible forms, processes, and ecosystems in the course of natural *mimesis*. It is not nature itself that is deficient, but only our mimetic access to it. Technological *mimesis* has access only to the forms, processes, and ecosystems that emerge in the course of natural *mimesis*, but not to nature as origin of these supplementary forms and processes, i.e., nature as *terra incognita*. The deficiency of nature concerns a deficiency in our access to nature as origin of natural *mimesis,* which remains a *terra incognita* for us, in contrast to nature as a mimetic form, process, or ecosystem that is accessible in technological *mimesis* (Blok 2019; Zwier, Blok, and Lemmens 2018). This deficiency of technological *mimesis* indicates not only an epistemic limitation on the lessons that can be drawn from nature, but also an ontological limitation: the dynamic

complexity of Earth's ecosystems indicates that nature's mechanisms, principles, and processes are highly complex, evolving, and therefore always uncertain.

The fundamental uncertainty of technological *mimesis* resulting from the deficiency of our access to natural *mimesis* introduces a fourth characteristic of the supplementary nature of *mimesis* that can inform a regenerative sustainable concept of biomimetic design, engineering, and technology. If the origin of natural and technological *mimesis* withdraws itself in the supplementarity of *mimesis*, that is, shows itself for the first time thanks to the supplementarity of *mimesis*, this supplement is *always* improper with regard to its origin: it is modified or supplemented by it. In other words, the constitutive nature of the supplementarity of *mimesis* implies not only that there is a duality between the mimetic form, process, or ecosystem that can be mimicked properly or improperly and its origin (*terra incognita*), but also that all *mimesis* will always be improper with regard to this origin (Lacoue-Labarthe 1999). We call this the structural limitation of technological *mimesis*.

A concrete example can be found in the Eastgate Centre in Harare, a green building in Zimbabwe modelled on termite mounds. After the building was finished, it turned out that the engineers based their design on an improper conception of how termite mounds actually work (Turner and Soar 2008). This example of an improper technological *mimesis* with regard to the original shows the uncertainty and limitation of biomimetic technologies in their effort to mimic nature. Although the ambition of *mimesis* is to mimic (un)differentiated nature, the deficiency of nature at an epistemic and an ontological level makes any constitution of biomimetic design a temporary and finite solution in light of (un)differentiated nature. This does not necessarily mean that an improper *biomimesis* is a bad thing: the temperature in the Eastgate Centre is successfully regulated without conventional air-conditioning and heating, and, with this innovation, the centre actually emits significantly less CO2.

The structural limitation of technological *mimesis* can be found in various forms. For instance, direct imitations of biological prototypes—e.g., the imitation of birdwings in a biomimetic technology that enables humans to fly—often fail. Another indication of limitation can be found in successful biomimetic technologies that can claim to be *more* efficient, *less* toxic, and so on, but are not yet *as* regenerative as their natural counterparts. An example is Sto SEA Lotusan, a self-cleaning facade paint that mimics the lotus leaf. The painted surface remains clean because dirt particles are unable to obtain a hold. Although the paint successfully mimics the lotus leaf as facades remain clean, it is also criticized because

toxic nanoparticles are emitted to the environment. The structural limitation of technological *mimesis* is also indicated by successful biomimetic technologies that mimic one particular biological strategy or function to achieve one particular result—e.g., a sticky adhesive, a self-cleaning surface—but are not embedded in, and mutually beneficial for, both the design and the natural ecosystems of planet earth like their natural counterparts. An example can be found in biomimetic solar panels that mimic the function of leaves: although a solar panel produces much more energy than the leaf of a tree, leaves do much more because they also produce oxygen, transport water, and are fully biodegradable.

These examples of the structural limitation of technological *mimesis* bring us to the conclusion that biomimetic design can always be criticized and should be open to revision—especially if new insights into the workings of nature show that the design is not responsive to Earth's ecosystems, let alone regenerative by design. The structural limitation of *mimesis* is the fourth characteristic of the supplementarity of *mimesis* that can inform a regenerative concept of biomimetic design, engineering, and technology. Although technological *mimesis* as differentiation of a technological design *beyond* the biosphere that remains embedded in and participates with this biosphere is a necessary and sufficient condition for biomimicry as regenerative design, every design remains (in principle) open to criticism and improvement.

From our reflections in this section, we can characterize biomimicry as regenerative sustainable design, engineering, and technology with the following four characteristics:

1. Technological *mimesis* is a *participative differentiation* of nature. It differentiates a technological design beyond the biosphere while remaining embedded, and participating, in this biosphere. It is participative to the extent that technological *mimesis* does not invent something completely new but instead finds its point of departure in the ecosystems of planet Earth and remains embedded therein;
2. The participative differentiation of *mimesis* is not restricted to *technological mimesis*; technological *mimesis* supplements natural *mimesis* in biomimetic design;
3. The participative differentiation of technological *mimesis* is *constitutive* of nature (forms, processes, ecosystems, principles);

4. Because of the constitutive role of *mimesis*, the participative differentiation of technological *mimesis* always remains limited in its effort to mimic nature.

4. Conclusion

In this article, we raised the question of how to explain the difference between traditional design, engineering, and technology—which have *exploited* nature and put increasing pressure on Earth's carrying capacity since the industrial revolution—and biomimetic design—which *explores* nature's sustainable solutions and promises to be regenerative by design. To answer this question, we reflected on the concept of *mimesis*, as it assumes a continuity between the natural environment as a regenerative *model* and *measure* for sustainable design that is *imitated* and *reproduced* in biomimetic design, engineering, and technology.

We first discussed how *mimesis* is conceptualized in the philosophical tradition to show that the concept cannot be understood with reference to classical categories like imitation and invention and instead introduces a completely new category. We conceptualized the supplementarity of *mimesis* in terms of two interdependent boundary conditions: differentiation and participation. In §3, we applied this conceptualization in the context of *biomimicry* and developed four characteristics of the supplementarity of *biomimesis* in biomimicry.

The four characteristics of technological *mimesis* developed in this article enable us to conceptualize biomimicry as a genuinely circular approach to regenerative sustainable design. These four characteristics of technological *mimesis* also enable us to distinguish between traditional exploitative design and biomimetic explorative design. Although a technological *mimesis* of natural forms or processes *potentially* leads to the reduction of waste and the improvement of resource efficiency, regenerative sustainability is not yet guaranteed in theory or practice. The four characteristics of technological *mimesis* developed in this article provide such a necessary and sufficient condition for biomimicry as regenerative sustainable design, as it requires biomimetic technologies to participate with and be embedded in earth's ecosystems. Furthermore, our concept of technological *mimesis* was able to address three critical issues around the concept of *mimesis* in biomimicry that have emerged in theory and practice. In this regard, our concept of technological *mimesis* enables both theory and practice in biomimicry to look beyond current approaches that focus narrowly on *mimesis* of natural forms and processes without taking advantage of the opportunities for regenerative design provided by nature, and to engage in biomimicry as regenerative sustainable design.

Future empirical research should further operationalize and validate these four characteristics of technological *mimesis*. New avenues for future conceptual research are also opened by the findings in this article: First, future research should analyse the relation between biomimicry and innovation. Although biomimicry may still give the impression of being oriented on the past—as it starts with what is given in natural *mimesis* that is subsequently mimicked in technological design—biomimetic innovation is also radically futural, as it creates something completely new. Future research should therefore consider the four characteristics of technological *mimesis* from the perspective of innovation. Second, future research should analyse the level of analysis in biomimetic design, engineering, and technology. Biomimicry is often considered at the level of forms, processes, and ecosystems, but philosophers of technology argue that artefacts always interact with a milieu or environment in which they can emerge and operate. Future research should consider in more detail the role of this biomimetic design milieu. Third, even if technological *mimesis* can claim to be regenerative sustainable design, it is not necessarily ethically preferable. Natural *mimesis* is the result of 3.8 billion years of trial and error, with the consequent loss of generations that did not succeed in the struggle for existence. Technological *mimesis* would require management practices to prevent the death and despair involved in natural processes (Rolston 1979). These management practices have already moved beyond natural *mimesis* in technological *mimesis* (Blok and Gremmen 2016) because, contrary to nature, a genuinely circular approach to regenerative sustainable design, engineering, and technology should also be ethical.[9]

Notes

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1. It is important to note that Aristotle does not explain which natural principles are mimicked in the construction of a house, but argues the other way around. “If, then, artificial processes are purposeful, so are natural processes too; for the relation of antecedent to consequent is identical in art and in Nature” (Aristotle 1980, 199a 20–25). Thus, the natural principles are in fact derived from technological principles. This is not a problem if it is assumed that nature and technology are essentially the same, as

is the case in Aristotle, but becomes questionable if we do not accept such a continuity between natural and technological processes, as argued for in this article.

2. Aristotle refers to the notion of purpose, which is at odds with the Darwinian view on evolution. This is not problematic for our argument, as the naturalistic concept of mimicry we introduce here is not necessarily teleological but indicates the imitation of the naturally given, whether this given is teleological or not.

3. The same twofold can be found in traditional conceptualizations of *mimesis* as re-presentation and re-production of nature. *Re-* means 'again,' 'anew,' 'once more,' and therefore always involves a supplementary A^1 in addition to the original A. So, even if one rejects our previous argument against the technological conceptualization of nature (*auto-poiesis*) and prefers the reproductive nature of *mimesis*, the same twofold principle is at stake.

4. This idea is supported by the history of the concept. In history, *mimesis* is not always seen just as a copy of the original, but also as a variant of the original (Godin 2015, 228). The contrast between imitation and invention, for instance, is a relatively recent conceptual development, because, originally, imitation was not opposed to invention but involved a variation of the original (Godin 2008). Only from the perspective of the modern idea of the 'new' does imitation become a mere copy.

5. The conceptualization of mimesis as participation can already be found in Plato's *Republic,* in which he introduces *mimesis* as *methexis* (participation) of beings in the world in the eternal *idea* (Plato 1935). We transpose this idea of participation to the ecosystems of planet Earth in which each and every technological design remains embedded.

6. This embeddedness in natural phenomena also explains the remaining difference between *techné* (*mimesis)* and *episteme* (science) from an Aristotelian perspective. Whereas *episteme* turns away from natural phenomena in order to reflect on general patterns (*eidos*, *idea*, type, category) and achieves this stance by abstracting from these phenomena, *techné* (*mimesis*) articulates these general patterns insofar as they remain embedded in these natural phenomena. *Techné* (*mimesis*) does not primarily *make* and *produce* an artefact, but brings forth this general pattern *in* the artefact, like the shoemaker brings forth the *eidos* of a shoe *in* the fabricated shoe (Heidegger 2000).

7. The notion of participation is contested in contemporary philosophy. According to philosophers like Levinas, participation is always participation in a generality that reduces the singularity of ourselves and the other, and should therefore be rejected. Although one can argue that *mimesis* as perfection articulates such a generality—a type or category that reduces the singularity of the natural phenomena that are subsumed under these general terms—participation means something different in the context of *mimesis*, namely, the acknowledgement of the embeddedness of each mimetic variant in the original, i.e., in Earth's ecosystems as ontic-ontological condition for our

being-in-the-world, to which our technologies have to be responsive to preserve our being-in-the-world (Blok 2016b).

8. This alternative conceptualization of technological *mimesis*, which remains embedded in a natural *mimesis*, has consequences for the unique connection between *mimesis* and human existence, as assumed by Derrida and others. We can no longer argue that only human beings are characterized by the ability to mimic, because technological *mimesis* remains embedded in a natural *mimesis*. The further elaboration of our conceptualization of mimicry for the human condition is beyond the scope of this article.

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