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Agricultural Technologies as Living Machines: Toward a Biomimetic Conceptualization of Smart Farming Technologies

Vincent Blok and Bart Gremmen

Wageningen Universiteit, Wageningen, The Netherlands

ABSTRACT
Smart Farming Technologies raise ethical issues associated with the increased corporatization and industrialization of the agricultural sector. We explore the concept of biomimicry to conceptualize smart farming technologies as ecological innovations which are embedded in and in accordance with the natural environment. Such a biomimetic approach of smart farming technologies takes advantage of its potential to mitigate climate change, while at the same time avoiding the ethical issues related to the industrialization of the agricultural sector. We explore six principles of a natural concept of biomimicry and apply these principles in the context of smart farming technologies.

KEYWORDS
Agriculture; biomimicry; precision livestock farming; smart farming technology; technology

1. Introduction

Following the call for smart technologies in our current society (Hildebrandt, 2013) – ranging from smart cities to smart medicines and from smart meters to smart cars – a relatively new phenomenon in the agricultural sector is the application of smart farming technologies (Reichardt, Jürgens, Klöbe, Hüter, & Moser, 2009). By the integration of smart technology and the internet of things – in which computers, censoring devices, GPS systems but also robots and even animals communicate with one another and function autonomously in an integrated farm management system – farmers can reduce farm inputs (fertilizers and pesticides) and increase yields, while reducing emissions to the environment (Bos & Munnichs, 2016).

In precision livestock farming (PLF), the internet of things is extended to farm animals. PLF can be defined as 'the management of livestock production using the principles and technology of process engineering.… PLF treats livestock production as a set of interlinked processes, which act together in a complex network' (Wathes, Kristensen, & Berckmans, 2008). The introduction of this type of integrated farm management systems enables farmers to control the production process by monitoring and controlling animal growth, behavior and health, the production of milk and eggs, the physical environment of livestock buildings, and greenhouse gas emissions and other pollution to the environment. Furthermore, the exchange of information about estrus detection, health, milk

CONTACT Vincent Blok vincent.blok@wur.nl

quality, etc. enables supply chain actors to optimize coordination and efficiency throughout the supply chain.

Although Smart Farming Technologies provide economic, social and environmental opportunities for the agricultural sector, they also raise ethical issues associated with the increased corporatization and industrialization of the agricultural sector. PLF facilitates the further intensification of livestock farming and the emergence of mega stalls with various socio-ethical consequences (Bos & Gremmen, 2013; Harfeld, 2010). Another ethical issue is the possible alienation between animals, farmers and citizens because of the robotisation and digitalization of farm management systems. Finally, farmers have to share all kinds of information about their farm management with processors and retailers who can take (economic) advantage of this information. In this respect, PLF may lead to the concentration of economic power of the process industry and retailers as linking pin in matching supply and demand within the supply chain (cf. Bos & Munnichs, 2016). Therefore, we may expect society to be reluctant to accept smart farming technologies because of the ongoing industrialization of the agricultural sector. This will lead to a call for the human and natural scale of agricultural practices, notwithstanding the potential of smart farming technologies to feed the increasing world population and to mitigate climate change for instance.

This reluctance to accept the industrialization of farming practices can be understood as a resistance against the conceptualization of the natural environment as a commodity for human needs, in which nature's own strategies and principles of operation are neglected – natural animal growth and behavior for instance – and instead, nature is challenged to supply efficiently agro-food products as commodities in an instrumental economic exchange among chain actors. On the one hand, one can argue that agriculture as such can be seen as technology, i.e. as a practice in which the natural environment is instrumentalized (Kaplan, 2017; Porter & Rasmussen, 2009; Thompson, 2009). On the other hand, there seems to be a legitimate call for farming practices that are better embedded in the natural environment like multi-functional agriculture, organic farming, etc., which can already be recognized in current western societies, even if these practices are disadvantageous to feed the word and to mitigate climate change. Because of the potential advantage of smart farming technologies we raise the question how smart farming technologies can be conceptualized, which are no longer characterized by the exploitation, domination, instrumentalization and commodification of nature, but instead, are embedded in and in accordance with the natural environment.

According to the German philosopher Peter Sloterdijk, the twenty-first century is characterized by 'a paradigm shift in the basic idea of technology' (Sloterdijk & Heinrichs, 2006, p. 329). Emerging technologies like biotechnology and nanotechnology are increasingly biomimetic, embedded in and in accordance with the natural environment: 'It appears that we are for the first time on the threshold of a form of technology, which will be sufficiently developed to enable us to radically imitate nature' (Sloterdijk & Heinrichs, 2006, p. 329). One of the founding mothers of the concept of biomimicry, Janine Benyus, defines biomimicry or biomimetics as 'a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems' (Benyus, 2002, p. 1). Biomimicry provides a new and ecosystem-friendly approach to nature, which is no longer characterized by the domination and exploitation of nature, but by learning and exploration and cooperation with nature (cf. Sloterdijk, 2001, p.

228). Benyus for instance argues that the first industrial revolution is characterized by the domination and exploitation of nature, whereas the second – biomimetical – industrial revolution is characterized by learning from, and exploring, nature (cf. Blok & Gremmen, 2016). The pretention of biomimetic or homeo-technologies is that they act and perform in accordance with or are similar to the operation principles of nature and for this reason, can claim to be sustainable and embedded in the environment (Benyus, 2002; Todd, 2013).

In this article, we explore the concept of biomimicry to conceptualize smart farming technologies as ecological innovations which are embedded in and in accordance with the natural environment.[1] To the extent that biomimetic smart farming technologies *mimic* natural processes, it can claim to be 'natural' like organic farming (Haperen, van Gremmen, & Jacobs, 2012; Verhoog, Matze, Van Bueren, & Baars, 2003). But to the extent biomimetic smart farming technologies concern ecological *technologies*, it moves beyond the tendency of organic farming and permaculture to eschew modern agricultural technology (Stojanovic, in press). In other words, a biomimetic approach of smart farming technologies could take advantage of its potential advantages like mitigating climate change and feeding an increased world population, while at the same time avoiding the ethical issues related to the industrialization of the agricultural sector by traditional smart farming technologies. In Section 1.1, we explore the concept of PLF as one of the main examples of Smart Farming Technologies, based on a literature review, and in Section 1.2, we analyze the actual operating principles of nature which are mimicked in biomimicry. In Section 2, we explore six principles of a natural concept of biomimicry and in Section 3, we apply these principles in the context of smart farming technologies. It will turn out that biomimicry does not primarily consist in the imitation of the aesthetic form or function of a natural entity in our technological design, nor in the incorporation of processes inspired by natural technologies at macro-, micro- or even nano-level. It consists precisely in the incorporation of the self-organization and adaptability of living systems to new or changing circumstances in the environment. We conceptualize biomimetic technologies as 'living machines'[2] and propose a set of criteria for biomimetic smart farming technologies. In Section 4, we draw our conclusions and explore future avenues for research in biomimetic smart farming technologies.

1.1. Precision Livestock Farming

The aim of this section is to provide an overview and analysis of the design principles of PLF, a new concept that profoundly relies on technology. During the last decades PLF has slowly changed livestock production from a low-tech sector to a more and more digitalized high-tech sector and has been used to incorporate all kinds of technological developments, ranging from dairy cows (e.g. Automatic Milking Systems) to pigs (e.g. live weight measurement) and poultry (e.g. environmental data collection) (Lokhorst & Groot Koerkamp, 2009). Compared with traditional livestock management, PLF has the potential to monitor many aspects of livestock production, both simultaneously and automatically. Farmers routinely gather all kinds of sensory information from their animals to evaluate health, welfare and productivity. Due to a revolution in sensors and sensing techniques, data-based models, and wireless internet, PLF is able to improve information gathering and guarantee a degree of control over processes that was previously impossible.

From a more general perspective, PLF can be defined as set of technological tools, such as sensors, data-based models that rely upon automatic monitoring of biological and related physical processes in livestock (Wathes, 2009; Wathes et al., 2008). A more comprehensive definition of PLF is the application of the principles and techniques for process engineering to monitor, model and manage animal production (Wathes, 2009). The application is based on a closed loop model-based control system to provide automatic management information to meet a specific target (Aerts, Wathes, & Berckmans, 2003; Clark, 1988). Processes suitable for the PLF approach may include the animal itself, such as animal growth, the output of milk and eggs, some endemic diseases, and aspects of animal behavior. It may also include the physical environment of a livestock building, such as its thermal micro-environment and emissions of gaseous pollutants such as ammonia (Wathes et al., 2008).

In the 1990s, the concept of PLF was mainly applied in Europe to the growth of housed pigs and poultry, though in principle, PLF can be applied to any farmed species, including animals that are farmed extensively (Wathes, 2009)). Examples of PLF applications are: weight estimation of pigs via machine vision tools (Banhazi, Tscharke, Ferdous, Saunders, & Lee, 2011), and cough recognition of pigs (Guarino, Jans, Costa, Aerts, & Berckmans, 2008). The level of application depends on the economics of the species. For instance, low cost cameras, in combination with image analysis can be used to quantify animal's behavior, size, shape and weight, even in large flocks or herds. Sensors can also be directly placed on the animal, thereby placing the individual animal at the center of PLF. Sensors for dairy cows or sows are available and may be used to optimize production and provide early detection of poor welfare in individuals (Wathes et al., 2008).

In PLF specific requirements to control biological processes in animals are: (1) continuous sensing of the process responses (or outputs) at an appropriate frequency and scale with information fed back to the process controller; (2) a compact, mathematical model, which predicts dynamic responses of each process output to the variation of input and can be (at its best) estimated online in real time; (3) a target value and/or trajectory for each process output, e.g. a behavioral pattern, pollutant emission or growth rate and (4) actuators and a model-based predictive controller for the process inputs, e.g. feed or the environment (Wathes, 2009).

The future development of PLF will rely on three interrelated aspects. First, from a more restricted technological point of view, significant improvements in computer processing power have to be realized and also different sensor technologies have to be available (Banhazi et al., 2012). The second aspect suggested by PLF experts (see e.g. Lokhorst & Groot Koerkamp, 2009, 2011) is the development of PLF into a fully integrated system. Most pressing needs are data-based models with meaningful parameters, and control systems that can manage two or more interacting biological and/ or physical processes. The third aspect is the inclusion into PLF of societal values that are connected to sustainability. These values are usually reflected in the PLF target or trajectory. They may concern a particular level of animal welfare, environmental protection and/or efficient use of natural resources.

1.2. The Concept of Biomimicry

As an alternative for the conceptualization of the natural environment as a commodity for human needs, in which nature's own principles of operation are neglected and instead, nature is challenged and exploited in order to supply efficiently agro-food commodities in an instrumental economic exchange among chain actors, ecological approaches of technology and innovation received increasingly attention over the years. Biomimicry or biomimetics is an example of such an ecological approach of technology and innovation. It studies the design of natural systems – wetland and sand dunes to break up the waves and reduce their speed in coastal areas for instance – and then imitates these designs to solve human problems; flooding, storm surge and sea level rise due to climate change.

The evolution of nature is seen here as a process in which plants, animals and microbes were able to perfect themselves and learned to fly, swim, navigate, capture the sun's energy, etc.[3] 'In short, living things have done everything we want to do, without guzzling fossil fuel, polluting the planet, or mortgaging their future. What better models could there be'? (Benyus, 2002, p. 2; cf. Todd, 2013). According to Benyus, nature functions here as a model – photosynthesis, self-assembly, self-sustaining eco-systems, but also eyes and ears for instance – which designs and manufacturing processes are imitated by biomimetics in order to solve technological problems. The objective of these innovations inspired by nature is no longer to exploit the natural environment but to explore and learn from nature in our effort to respectfully imitate nature. Benyus provides the example of biomimicry in farming practices: 'In a biomimetic world, we would manufacture the way animals and plants do.… Our farms, modeled on prairies, would be self-fertilizing and pest-resistant. To find new drugs or crops, we would consult animals and insects that have used plants for millions of years to keep themselves healthy and nourished …. In each case, nature would provide the models: solar cells copied from leaves, steely fibers woven spider-style, … perennial grains inspired by tallgrass…' (Benyus, 2002, pp. 2–3). According to Benyus, the main lesson we can learn from nature is the 'hand-in-glove harmony' of natural systems, in which 'organisms are adapted to their places and to each other', which should inspire our future nature-based technological innovations.

According to Benyus, there are 9 laws, strategies and principles of nature behind the maintenance of the eco-systems of planet earth:

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything
- Nature rewards cooperation
- Nature banks on diversity
- Nature demands local expertise
- Nature curbs excesses from within
- Nature taps the power of limit

Although the nature of these 9 laws or strategies is not clear and calls for a philosophical reflection on the concept of nature which is presupposed in biomimetic practices (cf. §2), we first call attention for another problem which remains unsolved in the concept of biomimetics; the dualism between nature and (human) technology which is presupposed in biomimetic practices.

This presupposition becomes clear in Benyus concept of nature as a model, measure and mentor. If biomimicry studies the design principles of nature and then *imitates* these designs, if it uses these principles to *judge* the 'rightness' of technological designs, if it *learns* from nature's models and applies it in human technologies, a dualism between nature as that which is pre-given and copied by biomimicry and technology as its copy, a dualism between nature as normative standard and human technology which can be judged based on this standard, a dualism between nature as endless pool of learning opportunities and human technologies which are developed based on this learning experience is presupposed. The concept of biomimicry only makes sense in case there is a difference between that which is mimicked (nature) and that which is the product of this mimicking process.[4]

This dualism between nature and (human) technology also becomes clear in Benyus' focus on engineering, and in this respect, on 'human' problems which should be solved by technology[5]: biomimicry is the *conscious* emulation of life's genius (Benyus, 2002 (emphasis added). This emulation 'aims to mimic life, not to reproduce it' (Bensaude-Vincent et al., 2002). Contrary to the primacy of human technology in the exploitation of nature in the industrial age, in this dualist biomimetic approach of technology development, primacy is given to natures principles as model, as normative standard and as opportunity to learn from these natural principles. The ideal of biomimicry is not to bridge this dualism by reproducing life, but by 'doing it nature's way' in our technology, we mimic nature's principles and strategies in our technological design: 'In a biomimetic world, we would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibers, ceramics, plastics, and chemicals' (Benyus, 2002, p. 2). Doing it nature's way primarily means that technological developments imitate the design principles of nature, not necessarily to incorporate nature's design principles in our technological designs. Also philosophers of biomimicry like Henry Dicks and Freya Mathews presuppose a dualism between nature and human technology: technology should be designed *like* the operating system of nature and even collaborate with nature, not necessarily become natural itself (Dicks, 2016; Mathews, 2011).

There are at least two reasons to question this dualism. According to philosophers like the deep ecologists, but also more recent ones like Sloterdijk and Plumwood, the exploitation of planet earth is rooted in anthropocentric humanism, i.e. in the 'standpoint of mastery' of the human will to master and exploit the natural world as commodity for human needs (cf. Blok, 2014). This anthropocentric-humanism can be found in the work of some of the proponents of biomimicry as well, namely as eco-friendly and human-beneficiary solution (Stojanovic, in press; cf. Blok, 2017). According to Plumwood, this dualism also gave rise to the idea that human agency can solve the environmental crisis we face today by engineering and technology (Plumwood, 2002), which in fact consists in the exploitation of nature (Sloterdijk & Heinrichs, 2006, p. 330). In this respect, there are many examples of biomimetic technologies that just pretend to mimic nature in order to safeguard the future of planet earth, but can be characterized by the exploitation of nature (see Myers (2012) for examples). In other worlds, it is questionable whether biomimetic technologies provide climate smart solutions which are embedded in and in accordance with the natural environment, as long as they are embedded in dichotomies like nature-human, nature-culture, nature-technology.

A second reason to question the supposition of the dichotomy between nature and human technology is the 'paradigm shift in the basic idea of technology' in the twentieth century (Sloterdijk & Heinrichs, 2006,p. 329). Recent developments in technology and science like biotechnology, nanotechnology and synthetic biology show that they are not purely natural or purely technological, but hybrid forms of technology which are *similar* to nature. Sloterdijk calls these new forms of technology *homeo-technologies*, derived from the Greek *homoios*, i.e. 'similar', or 'alike'. In other words, new and emerging technologies show that a dualist perspective on biomimicry is no longer appropriate to conceptualize current developments in science and technology and call for a monist approach of biomimicry.

Because the concept of biomimicry presupposes a dualism between nature and human technology, it may be the case that Sloterdijk prefers to speak about homeo-technology instead. Although he conceptualizes homeo-technology as *imitation naturae* in his work, a shift can be seen from the imitation of nature to the *incorporation* of nature's design principles in technology and *vice versa*, like in biotechnology (cf. Zwart, 2009). Myers even goes so far to say that his concept of bio-design goes further than other bio-inspired approaches like biomimicry, because it specifically refers to 'the incorporation of living organisms as essential components, enhancing the function of the finished work. It goes beyond mimicry to integration, dissolving boundaries and synthesizing new hybrid typologies' (Myers, 2012, pp. 8–9)).[6] In this respect, we can characterize these technologies as bio machines or living machines. Sloterdijk believes that the integration of the biosphere and the techno sphere under the direction and guidance by human cognition can guarantee a sustainable future (cf. van der Hout, 2014, August).

This raises the question what principles of nature should be incorporated in biomimetic technologies. While Benyus introduced 9 principles of nature, Sloterdijk has completely different principles in mind, such as replication, selection and trans genesis.[7] In bionics, which concerns the supplementing or duplicating of neurophysiological characteristics of the human body by the integration of electronic devices and mechanical parts, again other principles seem to be at stake. Nature is seen here as a 'system that use information to achieve heightened regulation and control', and is understood 'in terms of the concepts of feedback, information, control, regulation, teleonomy' (Dicks, 2016, p. 10). This conceptualization of nature raises the question whether the proposed principles are in fact principles of nature or principles of technology which are applied to nature. Elsewhere, we explored three principles of nature in discussion with authors like Benyus and Sloterdijk (Blok, 2016). In the next section, we will first summarize these three principles of nature, before we apply them in the context of smart farming technologies.

2. The Principle of Conativity as a Principle of Nature[8]

According to Spinoza, 'each thing, as far as it can by its own power, strives [*conatur*] to persevere in its own being' (Spinoza, 1992: part 3 proposition 6). For Spinoza, this conativity is not an *ontic* will or impulse of living systems toward self-preservation, but an *ontological* principle of all beings: 'The conatus to preserve itself is the very *essence* of a thing' (Spinoza, 1992: part 3 proposition 7 (emphasis added)); conativity articulates and establishes the being or *identity* of beings. Furthermore, for Spinoza, this conativity is not limited to *living systems*, because *every* body is conative according to Spinoza. On the one hand, we can argue that conativity is not only a principle of living nature, but primarily a principle of matter, i.e. of each material body on earth.[9] On the other hand, we can argue that this concept of conativity of material entities extends the domain of the 'living' from the traditional animate to the 'in-animate', i.e. 'living matter' as key element in the generation and self-regulation of planet earth as a dynamic system (Vernadsky, 1998; Lovelock, 2006; Clark, 2011, p. 14).[10]

To what extent can we consider conativity to be *essential* for natural entities, i.e. to what extent does conativity articulate the identity of natural entities. In Spinoza's view, there is only one common substance – *Deus sive Natura* – which constitutes the universe. All natural entities we encounter in the world are *modes* or *modifications* of this one substance. As such a mode, each material entity is resistant to everything that can take its existence away, and this resistance is precisely the conativity or strive to preserve oneself as such a mode of the common substance (Spinoza: part 3, proposition 6). Conativity is essential then because it *differentiates* the identity of natural entities from the common but un-differentiated substance – it articulates and establishes the self or identity of the tree and the stone for instance *as* modes of nature (*self*-perseverance) – and prevents at the same time their relapse in this common substance (self-*perseverance).*

If we frame Spinoza's idea of a common substance in more profane terms and highlight the 'naturalistic' framework he introduces, we can say that all natural entities we encounter in the world – the stone, the tree, human beings – are modes or modifications of nature. As such a modification of nature, each natural entity strives to preserve itself (self-perseverance). But if this strive is *essential* for each natural entity, conativity cannot be understood at an ontic level as a struggle for existence of these entities, but at an ontological level as the impulse[11] in nature to differentiate and establish the identity of natural entities like stones and trees as modes of this un-differentiated nature.

The essentiality of conativity for natural entities shows in other words that conativity is not a will or power of natural entities to preserve themselves (*auto-poiesis)* but primarily a principle by which nature becomes delimited *as* stone, tree, etc. Conativity is literally an endeavoring, an effort, and the essentiality of conativity consists in its endeavor to articulate and establish the differentiated identity of natural entities *as* modes of undifferentiated nature. On the one hand, conativity is needed to differentiate and establish these natural entities from undifferentiated nature in which they are embedded (*self*-perseverance). On the other hand, conativity is needed to maintain and persevere these differentiations and prevent their relapse in undifferentiated nature again (self-*perseverance).* In this respect, the delimitation of the identity of natural entities by the conativity of nature can be seen as the philosophical origin of the notion of resilience in agriculture and food systems (Chiles, 2016; Minteer, 2008; Thomas & Kevan, 1993) and of the eight 'principle of Benyus, that nature curbs excesses from within', i.e. the principle behind the self-regulation of and the avoidance of the transgression of these limits of planet earth as a dynamic system, and its inhabitants.

A first round of reflection on a naturalist concept of conativity makes therefore clear, first of all, that conativity is not an ontic will or impulse of natural entities (*auto-poiesis*), but primarily consists in the articulation and establishment of the identity of natural entities as differentiations from undifferentiated nature. This is the first characteristic of conativity as principle of nature we can discern.

As a consequence, biomimetic innovation and technology should not only mimic or incorporate the aesthetic form of natural entities in their design, like in case of a sharkskin-inspired swimsuit – this would provide a superficial likeness to the natural world – but precisely these two aspects of self-perseverance in conativity, i.e. self-perseverance which can be associated with the articulation of the self or identity of technological entities (self-organization and self-design), the autonomy, adaptability and headstrongness in their growth, and their self-perseverance which can be associated with self-regulation, self-healing/self-repairing and resilience of natural entities. What is primarily mimicked of nature in biomimicry is the conativity as self-perseverance of nature.

Let us consider now a further consequence of conativity as articulation of the identity of natural entities as differentiations of undifferentiated matter: ‘I’ am not primarily conative but ‘I’ am the performative constituent of the conativity of nature. This means that conativity as a principle of nature consists in the endeavor to differentiate and preserve natural entities like stones and trees, me and you, from undifferentiated nature as modes of nature, which remain embedded in this conative or ‘vibrant’ materiality of nature (cf. Bennett, 2010). We can compare this endeavor to differentiate with Kauffman’s ideas about the *Origins of Order*, i.e. the spontaneous emergence of order out of chaos by the self-organization of complex biological systems (Kauffman, 1993). This reveals a second characteristic of the conativity of nature: undifferentiated nature itself is a non-identity – or chaos in Kauffman’s terms – that articulates the identity of natural entities – or order in Kauffman’s terms – without the possibility of being identified itself. Nature itself is always heterogeneous to and always transcending the identity of actual natural entities as differentiations (order) from undifferentiated nature (chaos).

With this a dualist concept of nature emerges, which fundamentally limits the opportunity to mimic nature. While the identity of natural entities can be mimicked, undifferentiated nature that articulates the identity of natural entities cannot be mimicked. The advantage of this dualist concept of nature is that it acknowledges the fact that we only have limited access to the width and depth of nature. This width and depth is not only an epistemic limitation of what is known – the earth as *terra incognita* – but also an ontological limitation. Aristotle already argued that *steresis* or absensing belongs to the self-emergence of nature. This tendency to withdraw itself can be found in the hardness and impenetrability of the things around us – the self-closedness of a stone, but also the ‘absence’ of a cow that gives birth to a calf – in the undifferentiated nature from which the identity of natural entities emerge, unfold and to which they recede again (Blok, 2016), but also in modern quantum mechanics: ‘Objects withdraw from each other at a profound physical level’ (Morton, 2013, p. 41).

This dualist concept of nature enables us to acknowledge both the design of nature which can be imitated or incorporated in biomimetic technology, and the complexity and heterogeneity of nature which puts a limit to our ambition to mimic and incorporate nature. A further advantage of the acknowledgement of the fallibility of biomimicry is that we no longer presuppose that biomimicry is intrinsically or ethically ‘good’, as is sometimes suggested by authors like Benyus and Sloterdijk (Benyus, 2002; Sloterdijk, 2001, pp. 230–231). Designs can be misused and designers can be biased or frailty and use their power for their own purposes (cf. Myers, 2012). On the one hand, this dualist concept of nature puts a limit to the monist conceptualization of biomimicry we encountered in the previous section, without reintroducing the classical dichotomy between nature and technology. This limit is not found in a dichotomy between nature and human technology, but in a dichotomy between differentiated nature (which can be mimicked) and undifferentiated nature (which cannot be mimicked). On the other hand, this dualist notion of nature may explain why biomimicry sometimes fails and is not always preferable. Biomimetic practices aim to mimic or even incorporate nature's principles, but because nature withdraws itself both at an epistemic and an ontological level, biomimetic technologies and innovation become fundamentally fallible because of missteps, misuse or controversy (cf. Myers, 2012). At the lowest level of consideration, it may turn out that it mimics the identity of natural entities which are still emerging or entities which are in fact already receded to undifferentiated nature for instance. But more important, the acknowledgement of the fallibility of biomimicry acknowledges a 'ceiling on our ability to order or regulate our transactions with the living' (Clark, 2011, p. 29). This acknowledgement seems to be highly relevant in the 'risk society' we currently live in (Beck, 1992), in which our ability to make final judgments about the future of present technologies is fundamentally limited.

But if we conceive conativity as a principle of nature, rather than as a principle of natural entities, the question is why undifferentiated nature differentiates natural entities like stones, trees and human beings that build the eco-systems of planet earth.

According to Spinoza, nature is not only conative but also *associative*, which means that the conativity of nature does not only articulate and establish natural entities as modes of nature that can affect other entities in the environment, but that these entities are in this at the same time *affected* by other entities, which are on their turn also constituted by the conativity of nature. According to Spinoza, each mode of nature is already a composition of simple modes, which are affecting and affected by each other, i.e. which are primarily *responsive* to each other and form the relatively stable bodies we encounter in the world, ranging from simple bodies like stones to complex bodies like human beings for instance. Or as Bennett puts it: 'because each mode suffers the actions on it by other modes, actions that disrupt the relation of movement and rest characterizing each mode, every mode, if it is to persist, must seek new encounters to creatively compensate for the alterations or affections it suffers. What it means to be a "mode", then, is to form alliances and enter assemblages: it is to mod(e)ify and be modified by others' (Bennett, 2010, p. 22).

If we conceptualize this associativity at an ontological level, i.e. at the level of nature that articulates and establishes the identity of natural entities, these entities are not only the product of the conativity of nature, because this conativity is at the same time responsive to the conativity of (other) nature.[12] This responsive conativity of nature articulates the relative stable bodies like stones, trees and human beings we encounter in the world. In the differentiation of material entities by the conativity *of* nature, these entities are at the same time constituted by their responsiveness *to* the conativity of (other) nature and build the relatively stable bodies and complex systems in which the identity of natural entities are interconnected and interdependent. A second round of reflexion on a naturalist concept of conativity reveals the responsiveness of conativity as a third characteristic of the conativity of nature.

This third characteristic of the conativity of nature puts the first characteristic – its self-perseverance – in another light. While the self-perseverance can still give the impression that nature is characterized by self-regulation and the avoidance of the transgression of these limits, and is then *restrictive* by nature, the associative responsiveness of nature makes clear that this responsiveness to nature is also the source of every new configuration and new differentiation of the identity of natural entities in the environment. The conativity of nature does not only consist in the constitution of simple modes of nature which are characterized by self-perseverance and therefore simply grow but already affecting and affected by other modes, which results in the differentiation of new and more complex modes, and form the relative stable bodies we encounter in the world, like stones and trees and human, etc. Because these stable bodies are constituted by the associative responsiveness of the conativity of nature, biomimicry cannot consist in the imitation or incorporation of one particular function of technological design, without considering the wider ecological context in which they emergence and fade away, ranging from the eco-systems in which they are embedded to the dynamic systems of planet earth on which they depend. If for instance solar panels mimic photosynthesis, this mimicking is only contributing to the self-perseverance of the solar panel if it is not dependent on non-renewable materials, and is embedded in the ecosystem of planet earth. The problem with such techno fix solutions is that it doesn't question the exploitative practices in technology development. Our concept of the associative responsiveness of the conativity of nature provides a principle of nature which is able to explore and learn from nature.

In Table 1, we summarize the findings regarding the principle of conativity as principle of nature and provide six principles of a natural concept of biomimicry.

Table 1. Six principles of a natural concept of biomimicry.

Principles of Nature:	Principles of a natural concept of biomimicry:
– The conativity of nature consists in the a) articulation and establishment of the identity of natural entities from undifferentiated nature (*self*-perseverance) and the b) prevention of their relapse in undifferentiated nature again (self-*perseverance*).	(1) Biomimicry incorporates the self-perseverance as self-constitution (autonomy, headstrongness) of the identity of natural entities (2) Biomimicry incorporates the self-perseverance as self-regulation, self-healing/self-repairing and adaptability of the identity of natural entities to new or changing circumstances.
– Withdraws itself (non-identity) in the a) articulation of the identity of natural entities, which b) limits the anthropocentric role of human monitoring and control.	(3) Biomimicry is fallible because it mimics or incorporates the identity of natural entities which emerge, unfold and recede again in the complexity and heterogeneity of nature. (4) Biomimicry acknowledges the limits of human monitoring and control in the eco-system, in which human actors are embedded.
– In the articulation of the self or identity of natural entities (differentiated nature), undifferentiated nature is a) responsive to the conativity of (other) nature and b) build the relatively stable bodies and complex eco-systems in which the identity of natural entities are interconnected and interdependent.	(5) Biomimicry is open to new or changing configurations of the identity of natural entities (6) Biomimicry does not only imitate or incorporate an aesthetic form or function of a natural entity, but considers the eco-system in which they emergence, unfold and fade away.

3. Application of a Natural Concept of Biomimicry in the Context of Smart Farming Technologies

Our discussion of PLF as a form of Smart Farming Technologies (SFT) in Section 1.1 makes clear that current practices cannot be considered biomimetic. The current design of sensors and geographical positioning and information systems (GPS/GIS) is primarily focused on cost efficiency, increased productivity and sustainability. The main focus of current practices of SFT is to monitor and control agro-food and animal production processes, in line with the way agriculture is traditionally seen (Thompson, 2009). One can argue that SFT achieve this goal in a way which is comparable with bionics. While in bionics, electronic devices and mechanical parts are integrated in the human body, in SFT, electronic devices such as chips and sensors are integrated in livestock. Proponents of SFT may even argue that integrated farm management systems *mimic* the information, feedback and control systems we can find in the natural environment. At the same time, we can argue that such a conceptualization of biomimetic SFT presuppose and are governed by a technological conceptualization of nature, namely as self-producing machine (cf. Blok, 2016; Dicks, 2016). This may explain the societal resistance against current SFT practices.

In Section 2, we explored a natural concept of nature which may lay the ground for biomimetic SFT. Biomimetic SFT can be defined as the incorporation of nature's principles in the design of integrated farm management systems. Biomimetic SFT treats livestock production as a set of integrated processes – self-organization, self-regulation, adaptivity, etc. – which act together in the growth and differentiation of the identity of natural and technological entities, which build the eco-systems in which they are interconnected and interdependent. The focus of biomimetic SFT is no longer on the monitoring and controlling of animal growth, behavior and health, as in the four requirements to control the agricultural process (cf. 1.1), but imitates and incorporates the six principles of a natural concept of biomimicry we distinguished in Section 2. Requirements like sensing of process responses, prediction of process output responses to a variation of inputs, the setting of ideal output responses and the identification of limiters and lubricants in achieving this output ideal will be replaced by the first two principles of a natural concept of biomimicry, and will be extended by the last four principles of a natural concept of biomimicry.

Although the full development of biomimetic SFT is beyond the scope of this article, and needs much more interdisciplinary research, we can illustrate a biomimetic conceptualization of SFT by providing good practice examples for the six principles in the context of the agricultural sector.

A first example of biomimetic SFT or more in general can be found in interventions that replace agricultural practices that lead to the depletion and pollution of water and soil resources by biomimetic practices. The Land Institute for instance uses natural prairies as a model to revolutionize modern agriculture (cf. https://landinstitute.org/). Prairies thrive without pesticides, no fertilizer, no irrigation, i.e. without any human intervention, while remaining healthy, fertile and resilient year after year. By using deep-rooted perennial plants (rather than annual – non-self-persevering – plants) like mammoth wild rye and Maximillian sunflower in polycultural agricultural systems (rather than monocultural agricultural systems), self-regulation, self-healing and adaptivity to changed circumstances like weather changes are enhanced, water and soil resources are maintained or even improved, while high yields can still be realized. In this example of increased resilience, we recognize the first two principles of a natural concept of biomimicry. Self-perseverance as self-constitution and self-perseverance as adaptivity is also secured by rejecting genetic modification: 'Genetic modification is a form of using biology – what we call "bio-assisted" – rather than learning from it. In bio-assisted processes we domesticate the producer. In biomimicry, we emulate the producer' (http://biomimicry.net/).[13]

Another example is the ZERI pigs farming system (cf. http://www.zeri.org/ZERI/Pigs.html), in which school boys form a closed-loop system by collecting the sludge from a local brewery, use it as substrate to grow mushrooms and feed for the pigs, while converting their manure in biogas and feed for fish ponds that are grown. In this system, the school boys are embedded in the farming process of mushrooms, pigs, bio digester and fish ponds, which provide food, jobs, energy and learning opportunities for them. In this example, we recognize principle 4 of a natural concept of biomimicry.

Another example is the ZERI Coffee Farming System (cf. http://www.zeri.org/). Because 99.8% of the coffee plant can be considered waste, a closed-loop ecosystem was mimicked in which those wastes are used again within the coffee farming system. By growing shiitake mushrooms on the coffee waste, feeding the residues to cattle and pigs, converting their manure in biogas and slurry, using the biogas to heat the mushroom farming and the slurry as organic fertilizer for vegetable gardens and coffee bushes, the farming system was closed. In this closed-loop ecosystem, we recognize principle 1, 2 and 4 as well, but because of its *closed* design,[14] possibly not principle 5.

This principle is explicitly acknowledged in the example of living machines by John Todd (cf. http://www.toddecological.com/). In this example, a sludge-filled lagoon of a chicken processing facility was transformed into a flourishing ecosystem and wastewater treatment facility by creating a complex ecosystem with native plants providing a habitat for microbial communities which are important in the wastewater treatment process. The wastewater passes four distinct aquatic ecologies – plant root zones, fabric media, sludge mounds and open water – in order to clean the water. Contrary to closed-loop ecosystems like in the previous example, the lagoon is an open system into which several local plants and turtles have migrated. Also in other projects, Todd added 'wild ecologies' or 'wild environments' of species to tanks with different levels of wastewater in order to enhance natural wastewater treatments. Other examples can be found in the integration of biological pest control or the incorporation of animals like wasps in fruit production. In these self-designing and self-organizing 'wild' ecosystems, we recognize not only principle 1 and 2 but also principle 5. Also principle 4 is acknowledged, as the Intervale Eco-Park example shows (cf. https://makinglewes.org/2014/02/24/intervale-eco-park-burlington-usa/). Intervale is a living machine as well and a core part of the community food system: waste heat from a biomass plant warms greenhouses of local farms, while community food waste and industrial waste water are mulched into fertilizer by Intervale, which is then used by the farmers. In this way Intervale is embedded in the local food system. Also principle 6 is acknowledged in this example, because the wild ecologies which are part of the living machines acknowledge the importance of millions of organisms – micro fauna and microflora – to grow plants and break down chemicals (cf. Baskin, 1997).

The examples provided can still be considered low-tech, but this doesn't imply that biomimetic SFT are necessary low-tech. The Clear project of Wageningen University in the Netherlands for instance developed an agricultural production system that improves aquatic ecosystems, enhances nutrient cycling and is also more sustainable by mimicking two natural recycling systems, i.e. a combination of low-tech – putting a riparian-like vegetation around the field in order to limit nutrient runoff by re-incorporating them into the vegetation – and high-tech interventions – a technological filtration system which is inspired by the functioning of the kidney and filtrates and rejects unwanted compounds, while re-absorbing compounds which can be re-used in the system (http://challenge.biomimicry.org/en/custom/gallery/view/2519). Another example can be found in the dairy sector where PLF has emerged with the concept of automatic or robotic milking (AM system). An AM system is equipped with electronic cow identification, cleaning and milking devices and computer controlled sensors to detect e.g. abnormalities in milk. The system also provides remote notification to the farmer if intervention is required (De Koning, 2010). Because the cows are free to visit the AM system, they have regained a part of their autonomy, an illustration of principle 1.

While we provided examples of five out of the six principles that can at least inspire future biomimetic SFT practices, a real-life example of principle 3 couldn't be found in practice. This may be explained by the fact that the concept of biomimicry is still theoretically underdeveloped and that proponents think that biomimicry is intrinsically or ethically 'good' (Stojanovic, in press). Another explanation could be that proponents of biomimicry acknowledge the fundamental role of change – changed weather circumstances for instance – but highlight the importance of diversity and resilience to meet these changed circumstances, rather than the acknowledgement of failure. Nevertheless, we think that biomimetic SFT should take this fallibility into account in order to prevent too high expectations of biomimicry as a panacea for all human problems due to the industrial age.

4. Conclusion

In this article, we raised the question how SFT can be conceptualized, which are no longer characterized by the exploitation, domination, instrumentalization and commodification of nature, but instead, are embedded in and in accordance with the natural environment. To this end, we explored a biomimetic conceptualization of SFT in this article.

In Section 1.3, we defined biomimetic SFT as the incorporation of nature's principles in the design of integrated farm management systems. Biomimetic SFT treats agricultural production as a set of integrated processes – self-organization, self-regulation, adaptivity, etc. – which act together in the growth and differentiation of the identity of natural and technological entities, which build the eco-systems in which they are interconnected and interdependent. Biomimetic SFT imitates and incorporates the six principles of a natural concept of biomimicry we distinguished in Section 2. One can raise the critical question now what is new if we compare biomimetic SFT with the longstanding tradition of trying to be more natural in agriculture. There is nothing new to the extent that biomimetic SFT, just like organic farming and permaculture, can be seen as mimicking natural processes. But there is something new at stake in biomimetic

SFT to the extent that it explicitly relies on technology and can therefore be contrasted with the tendency of organic farming and permaculture to eschew modern agricultural technology. Although biomimetic SFT is still in its infancy, the examples in Section 3 provide at least evidence that biomimetic SFT is principally possible and is a progressive avenue to mitigate climate change and feeding an increasing world population, while better embedded in the natural environment at the same time. Because biomimetic SFT doesn't conceptualize the natural environment as a commodity for human needs, but incorporate nature's own strategies and principles of operation in our technological design, it is expected to have important advantages over current SFT practices.

This research is only the first step in the conceptualization of biomimetic SFT. Future research should focus on the design of integrated farm systems, based on the six principles of a natural concept of biomimicry, and test its applicability in practice, as well as the concrete economic, social and environmental advantages and disadvantages of biomimetic SFT compared with current practices. Finally, the ethical advantages and disadvantages and the societal embeddedness of biomimetic SFT should be assessed and evaluated. Of special interest is the further integration of rural and urban areas in agricultural practices, and the opportunities biomimetic SFT provides to achieve such integrated agricultural practices.

Notes

1. In this article, we use the terms smart farming technologies and precision livestock farming interchangeably.
2. We derive this term from the work of John Todd, although it will turn out that we conceptualize living machines in a rather different way than he did. Nancy and John Todd use the term living machines to characterize the use of natural systems to solve technological problems, for instance natural restorers to treat sewage and purify water (Todd & Todd, 1994) (cf. Section 3).
3. Framing natural processes in terms of strategies and principles implies that nature is intentional. From an evolutionary perspective, one can criticize the existence of unchanging principles like the ones proposed by Benyus. Although an in depth elaboration of this assumption is beyond the scope of this article, we argue that the principles we will introduce in Section 2 are at least partly consistent with the evolutionary perspective.
4. Although philosophers of biomimicry like Freia Mathews are more nuanced in this, they also adhere to a remaining duality: 'what seems to be needed to avoid this standoff [the crude dualism between nature and humanity] is an inclusive conception of nature, one that accommodates both the human and the nonhuman components of the greater life system, without collapsing the distinction between them' (Mathews, 2011, pp. 365–366).
5. Forbes for instance argues that natural systems 'can be directed to work in novel ways to suit our purposes' (Forbes, 2005, p. 6).
6. Although a shift from imitation to incorporation can be signaled in the term bio-mimicry, homeo-technology and bio-design, we continue the use of the concept of biomimicry because 'incorporation' and 'integration' doesn't oppose the basic idea of biomimicry. Instead, it can be seen as key characteristic of a *monist* approach of biomimicry.
7. To make it even more complicated, in the conceptualization of naturalness in agriculture, at least four different notions of nature are used (cf. Sagoff, 2003; Thompson, 2003; Verhoog et al., 2003).
8. Parts of this subsection are published in Blok (2016).
9. The distinction between *living* nature and *dead* matter is already questioned as a typical *modern* distinction (Jonas, 1966). According to Folz, the distinction between *phusis* (nature)

and *zoe* (life) consists in the fact that *zoe* 'designates a particular character of *phusis* within which self-emergence is intensified' (Folz, 1995, p. 132). But nature is often identified with life, or as whitehead puts it: 'Neither physical nature nor life can be understood unless we fuse them together as essential factors in the composition of "really real" things whose interconnections and individual characters constitute the universe' (cited in Folz, 1995, p. 131). Contrary to Folz, we claim that the expansion of our concept of 'life' to include nature at large provides a concrete principle of nature which can be used in biomimetic practices. In this article, we conceive conativity as a principle of the materiality of planet earth, thus including nature.

10. While Peter Forbes, one of the proponents of biomimicry, argues that 'what makes bio-inspiration possible is the miracle that nature's mechanisms do not have to be "alive" to work' (Forbes, 2005, p. 5), we argue here that we have to extent the domain of the 'living' to the in-animate or materiality in our concept of biomimicry.
11. *Conatio* is a translation of the Greek *horme*, impulse or onset.
12. One can argue that, as long as matter is undifferentiated, it cannot respond to anything other because, prior to difference, there is nothing other for it to respond to. Although we can argue that the traditional concept of causality is inappropriate to conceptualize the *event* of responsive conativity, the question makes clear that future research should be dedicated to this event character of responsive conativity.
13. Based on Thompson's (2009) distinction of various concepts of nature operating in the agricultural sector, we can argue that this assessment has to be nuanced and requires a more in depth analysis. See Zwart (2017) for an promising way to reconceptualize biotechnology in a biomimetic way, as well as Biddle (2017) for a proposal to innovate responsibly in genetic engineering.
14. The closedness of this system is relative since one can argue that all systems are 'open' unless humans construct boundaries of the system in order to enhance control.

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ORCID

Vincent Blok http://orcid.org/0000-0002-9086-4544

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