Journal of Agricultural and Environmental Ethics (2025) 38:26
https://doi.org/10.1007/s10806-025-09963-3

ARTICLES

Towards a Method to Reflect on Foundational Structures: The Case of Precision Farming

Mariska Thalitha Bosschaert[1]

Received: 25 June 2025 / Accepted: 12 September 2025

Abstract

In contemporary agriculture, the paramount challenge lies in feeding an ever-growing global population while concurrently mitigating the impacts of climate change. Over recent decades, precision agriculture has emerged as solution to this challenge, utilizing advanced technologies to monitor to the specific needs of individual plants and animals. Alongside these high expectations, several concerns have been raised regarding precision farming. These concerns span various kinds of social structures, including impacts on individual farmers and farming globally. Concerns that have received less attention so far are related to meta-physical structures. Meta-physical structures are foundational structures that pertain to how we understand and experience the world—what we take to be self-evident. For instance, how we automatically distinguish between crops and weeds, even though there is no inherent difference. There are strong indications that the focus of the farmer from direct observation to digital screens will change the farmer's experience of fields, plants, and animals. Since this is about what we regard as self-evident, it is very difficult to reverse course once these structures have changed. Therefore, it is crucial to reflect on these structures early in the development of precision farming. Currently, there is no established method to relate meta-physical structures with concrete practices such as precision farming. Therefore, a method to reflect on meta-physical structures will be developed in this paper and applied to precision farming. The evolutionary perspective of Gilbert Simondon will be proposed as a basis for this method.

Keywords Precision farming · Ontology · Simondon · Digitalization · Structures

✉ Mariska Thalitha Bosschaert
mariska.bosschaert-bakhuizen@wur.nl

1 Philosophy Department, Wageningen University & Research, Wageningen, The Netherlands

Published online: 07 October 2025

Introduction

Since the 1980s, digital technologies have been increasingly deployed to enhance efficiency in agriculture (Mulla & Khosla, 2015). More recently, the integration of big data and the Internet of Things has given rise to what is now termed precision farming. Precision farming encompasses technologies such as GPS, drones, smart cameras, sensors, and automated feeding systems, and is applied across diverse agricultural domains including cropping systems, fisheries, forestry, and animal husbandry (Beluhova-Uzunova & Dunchev, 2019). Digitalizing all agricultural assets aims to enable farmers to address the specific needs of individual plants and animals, thereby improving efficiency, increasing productivity, and mitigating the impacts of climate change (Beluhova-Uzunova & Dunchev, 2019; Karunathilake et al., 2023).

Expectations surrounding precision farming are high. It is anticipated to reduce agriculture's environmental impact while still feeding the increasing human population (Karunathilake et al., 2023). However, scholars have also identified several concerns regarding various types of social structures (Karunathilake et al., 2023; Monteiro et al., 2021). Regarding individual structures of human-technology interaction, precision farming demands new skills, raising questions about farmers' capacity to manage these new technologies and the potential stress involved. Regarding local social structures, the substantial investments required for equipment and education may be inaccessible to farmers in developing regions, where energy and internet infrastructure are often limited. This could exacerbate global inequalities and lead to job displacement. These concerns are region-specific. There are also concerns that will affect farmers globally, as farmers will collect much data that is stored in the cloud, which can be misused by large corporations. The concerns at the various levels can be regarded as social structures, for they all concern how humans relate to each other and interact with each other, to large corporations, to their work, etc.

Precision farming thus is not merely a collection of digital technologies that will only enrich the practice of farming. These technologies are embedded in various social structures that all require reflection on the impact of precision farming. A type of structure that has received less attention so far are meta-physical structures, structures that are foundational to human life in a certain age. Meta-physical structures are not yet another level, but are structures of how we understand and experience the world in which we live and act. To grasp meta-physical structures, it is important to distinguish between the things we can measure and the things we automatically accept about the world, i.e. the things which are self-evident to us (Blok, 2024). Applied to farming, we can automatically distinguish between crops and weeds in a field. However, when considering edible weeds, there is nothing inherently distinguishing them as weeds. Nonetheless, we automatically recognize and seek to remove them. This is how we experience and understand these plants. What we assume about the world are thus not properties of the things themselves, but pertains to what we regard as self-evident about the world. This thus is also structural for it affects how we relate and interact with each other and the world. However, it is not a social structure, but meta-physical, since it is not about the properties of the things but about how they are experienced and understood.

Meta-physical structures are not static but dynamic and this paper hypothesizes that they are currently shifting due to the integration of digitalization into farming. If farmers increasingly rely on computer screens to assess fields, plants, and animals, rather than direct observation, this reliance on digital technologies could impact their trust in their own observational capabilities. If farmers begin to experience fields, plants, and animals differently and cease using their own senses to assess plant and animal health, they could miss out on essential information necessary for successfully cultivating these organisms. The relevance of meta-physical structures lies precisely here: such a shift may fundamentally alter how agricultural assets are experienced and understood. Future farmers may no longer recognize the value of direct observation—not because it is impossible, but because it is experienced as outdated. This is analogous to the decline of paper-based administration, which, despite its resilience to digital failures, is now rarely used.

Changes in meta-physical structures are difficult to reverse. Therefore, it is important to reflect on the direction of how these structures are developing and what the potential negative implications are. This will make early intervention possible. However, no concrete method currently exists for reflecting on meta-physical structures within a certain practice. A proposed methodological outline suggests that, since meta-physical structures are not abstractions of sociological ones, they should not be studied through inductive or deductive methods. Instead, they require 'sideways' reflection—to thematize what typically remains unthematized or self-evident (Blok, 2024). The challenge in thematizing what is self-evident is that it cannot be measured. We cannot choose how to experience something. The research question of this paper therefore is: What method is suitable for reflection on meta-physical structures in precision farming?

To address this question, Sect. "Reflecting on how the World in Which we Live and Act is Understood" proposes a method for reflecting on technological developments and their meta-physical implications. To reflect on technological developments, the evolutionary perspective of Simondon will be proposed, as his perspective enables to make explicit how technologies are related in a broader evolutionary process without inherent normative biases. Even though Simondon himself does not reflect on meta-physical structures, his perspective provides a solid basis for such reflection. In this section, a concrete method will be proposed that will be applied in Sect. "Digitalization in an Evolutionary Perspective" and "Reflecting on Meta-Physical Structures in Precision Farming". First, in Sect. "Digitalization in an Evolutionary Perspective", it will be elucidated how digitalization, which is basic to precision farming, is currently reshaping our experience and understanding of the world in which we live and act. Second, Sect. "Reflecting on Meta-Physical Structures in Precision Farming" explores how these meta-physical structures manifest within precision farming. The conclusion reflects on the method as a whole.

Reflecting on how the World in Which we Live and Act is Understood

This section aims to develop a method for reflecting on meta-physical structures in farming, i.e. what we consider self-evident. The evolutionary perspective of Gilbert Simondon will be used to facilitate this reflection. This perspective has two advantages. First, it situates technological developments within a broader evolutionary context, providing a solid basis for reflection on meta-physical structures. Second, it has the ability to describe evolutionary technological development without inherent normative biases. For instance, Albert Borgmann has reflected on farming but his notion of *focal things* inherently carries normative values. Focal things are societal elements that require protection, such as farming skills (Borgmann, 1984). While this notion is intriguing, it directs the analysis towards a specific normative direction from the outset.

SubSect. "Technical Objects in an Evolutionary Perspective" will focus on the technological evolutionary perspective of Simondon. Only aspects relevant to developing this method are discussed, omitting many parts of his theory. Both *Individuation in Light of Notions of Form and Information* (2020) and *On the Mode of Existence of Technical Objects* (2017) are utilized to elucidate his perspective. SubSect. "Criticizing Simondon" address some points of criticism regarding Simondon's theory to complete the theoretical framework, leading to the development of a method in subSect. "Turning Simondon's Perspective into a Method".

Technical Objects in an Evolutionary Perspective

Simondon was unsatisfied with existing accounts of what an individual is, which he critiqued for focusing on the being itself rather than the process in which they become beings, or in other words *how* beings become individuals. He illustrates this with the example of clay, arguing that we should not see the mold as form and the clay as matter, as the raw materials of both contain potentialities to create, for instance, a brick. A human is also involved in preparing these materials and to put them in the oven. In this way, the clay, mold, and human together enable the clay to get the desired shape[1] (Simondon, 2020). This shows that the human is also an important part of the individuation process of technical objects.

To shift the focus to *how* technologies become individuals, Simondon argues that the individual object is subject to evolution and will evolve into new types of individual objects and is thus a small part of a larger process. He illustrates this process with the example of a crystal, which starts with a small germ and grows in all directions. The supersaturated liquor in which it grows serves as the structures of the formation process. He thus regarded technological evolution a process in which technical objects, along certain structures and in various directions, become individuals. The germ represents the *pre-individual*. The pre-individual contains the potentialities of what later will become the individual. These potentialities remain present throughout the process, meaning that even when a technology has developed into a concrete tech-

[1] Simondon tries to get away from an Aristotelian perspective, nevertheless, the question is to what extent he succeeds in this. A discussion on this question can be found in Blok (forthcoming).

nology, the pre-individual still exists (Simondon, 2020). Susanna Lindberg explains this pre-individual as a situation with certain problems and technological possibilities leading to the development of new concrete technologies (Lindberg, 2019).

Since Simondon is focused on processes and not on isolated technological objects, he argues that this process is characterized by *metastability*. Metastability contrasts with both stability and instability. He argues that if an individual were completely stable, it could not evolve anymore into something else, but the concrete individuals are not unstable either. Thus, he borrowed the concept of metastability from thermodynamics (Simondon, 2020).

An example of metastability in agriculture is the tractor, which did not simply appear into history but replaced the horse in response to the growing population. In the early twentieth century, multiple tractor designs were developed to determine which best suited agricultural fields of the time (Eason, 1916; Rose, 1915). Today, engineers respond not only to population growth but also to climate change, developing smart tractors that are lightweight, electric, and autonomous (Chen et al., 2022). Although each generation of tractors may appear stable, the technology remains metastable and ready to evolve into new types. All technologies are thus part of a broader evolutionary process that never becomes fully stable and involves a pre-individual containing the potentials for the next phase.

When the pre-individual goes to the next phase, it resolves into an individual and its milieu. Simondon describes several milieus, but most attention goes to the associated milieu, which is the milieu it needs to function, such as the increased turbulence and heat in a helicopter when the rotors spin. However, this milieu will not be relevant to the method that will be proposed in 2.3. Simondon also describes other milieus, which are relevant, such as the natural, technical and geographical. The natural milieu is what a certain location offers a technology, like a dam or a coal mine that cannot be built just anywhere. The technical milieu includes the conditions needed for the object to function, such as a certain voltage. The geographical milieu involves environmental conditions, as a locomotive that must be strong enough to push through snow (Simondon, 2017).

According to Simondon, technologies thus do not simply appear in history but are part of an evolutionary process involving humans, human desires, technological possibilities, various kinds of milieus, etc. This perspective can help describe the fundamental changes brought by digitalization in agriculture. However, before deriving a method from Simondons perspective, first some points of criticism need to be discussed.

Criticizing Simondon

While Simondon's perspective is useful to situate concrete technologies in the broader context of their evolutionary process, three points of criticism need to be discussed.

First, Simondon's focus on the evolution of concrete technologies overlooks the broader technological evolutionary processes, where various technologies are interrelated and shaped by social and meta-physical structures. The broader evolutionary process is not a seamless progression process; certain technologies alter existing trajectories, giving rise to new kinds of technologies. Such discontinuities also change our experience and understanding of the world in which we live and act. For example, the steam engine lead to numerous new kinds of technologies powered by it. This not only triggered profound social transformations but also reshaped how humans and objects were understood, as described by Blok (2022a). Humans used the steam engine to convert energy from one form to another, namely coal to pressurized steam. As a result, both humans and objects started to appear as converters: humans became industrial workers, stones were converted into clay, etc. Although humans have always converted energy, humans and objects now started to be experienced as converters. Concepts like potential and kinetic energy developed in centuries following the invention of the steam engine (Ayres, 2016). Our understanding of humans and objects changed and our language was shaped accordingly. This new understanding had social consequences, as industrial workers were seen merely as converters, reducing the obligation to ensure good working conditions. A new understanding of the world in which we live and act thus also affects social relations. Thus, it is important to focus not only on the evolution of concrete technologies, but also on the technological evolutionary process as a whole and to question how discontinuous transitions in this process affects human understanding of the world, and more concretely for this paper, of farming.

Second, the milieus that Simondon describes have in common that they are all focused on the functioning of the object. Simondon does not consider how other kinds of milieus, as the economical or societal, influence the evolution of technologies. In case of society, Simondon argues that it is not a milieu because society is not a substantial whole, and that if the social were a milieu, the individual would not continue to transform (Simondon, 2020). What Simondon does not take into account is that social aspects and technologies mutually shape each other (Bijker, 1995), a mechanical tractor powered by fossil fuels can function very well today, however, the growing population and climate change require new types of tractors. It is therefore necessary to divert from Simondon on this point and to acknowledge milieus too that do not primarily concern the functioning of technologies.

Third, Simondon's description of the role of humans in technological evolution is too simplistic, suggesting that humans and technologies could always work together smoothly. In Simondon's example of humans creating a brick from clay, humans appear fully in control, rendering technological development a teleological process (Blok, forthcoming). Yet, as Lindberg (2019) notes, technological outcomes often diverge from intentions—such as nitrogen pollution resulting from intensive farming. While humans are a part of technological evolution and have concrete aims while developing technologies, technological evolution should not be seen as a teleological process. Instead, humans are one factor among many, navigating unintended consequences. The notion of *deviative responsiveness* addresses this omission by emphasizing how humans can diverge from how they would usually respond to technological possibilities, various milieus, etc. in the course of technological evolution (Blok, 2022b). This enables them to develop something that takes the evolutionary process in a new direction, as the steam engine did. The possibility to deviate from the course of technological evolution does not place humans outside the process—they still have to respond to various milieus and technological possibilities of their time.

Turning Simondon's Perspective into a Method

Building on Simondon's evolutionary perspective and the critiques thereof, this subsection proposes a method to explore how precision farming affects human understanding of farming.

Step 1. Identify the Epitome Technology

The first aim is to identify moments of discontinuity within the technological evolutionary process that gave rise to new possibilities and technologies. Unlike a historical account, which encompasses a broader array of events and individuals, this method focusses on discontinuity. Precision agriculture depends on digital technologies, which raises the question of where the transition to digital technologies occurred. By situating digitalization in an evolutionary perspective, it becomes possible to identify a technology that epitomizes this transition. The notion *epitomize* is used, for the technology is part of a larger evolutionary process that includes other technologies, human design, human desires, unexpected outcomes, various kinds of milieus etc. Hence, even though this technology epitomizes the transition, it is not solely responsible for it.

Step 2. Identify the Pre-individual Before and After the Epitome Technology

Once the epitomizing technology is identified, the next step is to reflect on the pre-individual phase. Why was this technology developed? What human desires drove them to develop this technology? How did the humans involved deviate from their responsiveness in this course of technological development? What technological possibilities did the engineers have at their disposal (technical milieu)? What other milieus allowed for this change to happen?

Following the phase shift, the pre-individual does not vanish but changes. This raises the question of what has changed. What new technological possibilities emerged? What new kinds of technologies were developed? What other milieus changed after the development of this technology? What new human desires emerged regarding technological developments following the advent of this technology? How did humans deviate from their responsiveness in the course of this technological evolution?

Step 3. Compare the Pre-individuals and Reflect on Changes in Understanding

This step extends beyond Simondon's perspective, as Simondon did not reflect on meta-physical structures. However, the analysis based on his perspective can serve as a solid basis to consider the implications in meta-physical structures. By comparing the pre-individual before and after the epitomizing technology will reveal what has fundamentally changed. Identifying this fundamental change provides the foundation for reflecting on how digitalization has changed human experience and understanding of the world, i.e. how digitalization changed meta-physical structures.

To guide this reflection, two key questions are posed to thematize the meta-physical structures that usually remain unthematized or self-evident:

A. In what ways does this fundamental change alter how things are experienced and understood?
B. What are the implications when this becomes the default way for experiencing and understanding things?

Step 4. Identify the Meta-Physical Structures in a Concrete Practice

The first three steps focus on reflecting on a major change in technological evolution that affects our experience and understanding of the world – namely the rise of digitalization. At this stage, the analysis is not yet specific to digitalization in agriculture. In step 4, it will be explored whether the meta-physical structures identified in step 3 can also be identified in the technological evolutionary process in precision agriculture.

Step 5. Reflect on Changes in Understanding in a Concrete Practice

Step 4 will show that the meta-physical structures found in step 3 are also findable in agriculture. Therefore, the next step is to explore what these structures mean for our experience and understanding of this practice. To this aim, the guiding questions from step 3 will be asked concerning precision farming too.

In the next two sections, this proposed method will be applied. Sect. "Digitalization in an Evolutionary Perspective" will be focused on step 1–3 and Sect. "Reflecting on Meta-Physical Structures in Precision Farming" on step 4–5.

Digitalization in an Evolutionary Perspective

In this section, step 1–3 of the method outlined in subSect. "Turning Simondon's Perspective into a Method", are applied to digitalization, on which precision farming relies. This exploration will make explicit the discontinuities in technological evolution due to digitalization. Clarifying this discontinuity will provide a foundation to explore the changes in meta-physical structures due to the rise of digitalization—that is, the changes in what we take as self-evident about the world in which we live and act.

What distinguishes digital technologies from other technologies is their reliance on the binary system of zeros and ones as well as their capacity to assume complex tasks. Tracing the evolution of these characteristics reveals not one, but two epitome technologies in the development of digitalization: the electric telegraph (binary system) and algorithms (assume complex tasks). The electric telegraph is part of a technological evolutionary process in which standardization has increasingly come to be taken as self-evident, as will be discussed in subSect. "Standardization". Algorithms are part of a technological evolutionary process through which we have come to place increasing trust in the 'judgment' of digital technologies, as will be discussed in subSect. "Trusting the Outcomes of Digital Technologies". In both subsections, steps

1–3 of the method as proposed in subSect. "Turning Simondon's Perspective into a Method" are elaborated.

Standardization

The electric telegraph was developed to enable long-distance communication. The human desire to communicate over great distances dates back to antiquity, when tools such as smoke signals and mirrors were employed. While effective, these methods were limited in range and information capacity. Binary systems eventually proved to be the most efficient means of long-distance communication. An early example of such a system can be found in the use of shutters in lighthouses, which turned the light on and off at predetermined intervals (Agrawal, 2016; O'Regan, 2018). In the nineteenth century the electric telegraph was developed, operating on a binary system of dots and dashes.

Although not zeros and ones, the electric telegraph marked a significant transition by enabling rapid information transmission across the globe. This technology was no longer optical, enabling humans to transmit information beyond the line of sight. This new possibility impacted not only local structures, but facilitated global agreements, such as a global economy and standardized time. These developments influenced how humans understood themselves, with a notion like world citizenship emerging as early as the late nineteenth century (Müller-Pohl, 2010; Zerubave, 1982). Given that binary systems are foundational to digital technologies, and considering the transformative changes brought about due to the telegraph's binary nature, the electric telegraph should be regarded as an epitome technology in the evolution of digitalization—even though it is not a digital technology in itself.

The primary challenge that led to the development of the electric telegraph was the need for long-distance communication. While ideas for an electric telegraph already existed in the eighteenth century, it was not until the nineteenth century that the understanding of electricity was well enough that a functional telegraph capable of transmitting messages beyond the line of sight was realized (Altmann, 2023; Wheen, 2011). The integration of Morse code (binary system) completed the aim of relatively rapid long-distance communication (Wheen, 2011). At this stage, the telegraph was primarily focused on fulfilling the ancient human desire to communicate across distances.

However, as the telegraph became widely adopted, it enabled new possibilities. It facilitated the standardization of economic systems through the exchange of price information between cities and, eventually, across continents (Carey, 2018). It also enabled time synchronization across regions (Rikitianskaia & Balbi, 2021; Wheen, 2011), which was essential for developing regular public transport without the risk of collisions (Rikitianskaia & Balbi, 2021; Zerubave, 1982). Humans thus deviated from their responsiveness to the evolutionary process in which long distance communication was the aim, for they increasingly started to standardize society.

By the mid-twentieth century, it was discovered that all forms of information could be converted to zeros and ones and transmitted via the same networks. This discovery boosted the use of this binary system, which became foundational to all digital technologies. The ability to reduce all information to two variables enabled the development of systems capable of performing increasingly complex tasks (O'Regan, 2018; Wheen, 2011).

Although the electric telegraph is not a digital technology itself—operating on a different binary system—it epitomizes the transition from the human desire for long-distance communication to standardization of society. Standardization, therefore, is not limited to digital technologies; it has permeated society so thoroughly that it has become self-evident. If someone is 5 min late, they are likely to let others know that they are late; vegetables are standardized, with crooked cucumbers being rejected; information is synchronized across various devices; the industry is shaped to produce many standardized products. Conversely, in a world where standardization is the norm, non-standard experiences—such as custom-made furniture–are experienced as unique or special. These examples illustrate how deeply standardization shapes the world we live and act in and how it has become self-evident.

Standardizing everything has become as self-evident that it often goes unnoticed. For instance, since the COVID-19 pandemic, online meetings have become commonplace. Such meetings appear to be equivalent to in-person meetings because participants can see and hear each other. However, the information that is exchanged online is transmitted digitally and thus converted to zeros and ones. As a result, subtle elements such as non-verbal cues and group dynamics are diminished. Therefore, group-dynamics offline and in-person differ (Macchi & Pisapia, 2024; Souza et al., 2024). Standardization through digital systems thus entails a loss of certain meanings. An important implication of standardization through zeros and ones as the default way to understand and experience the world thus is that, despite the advantages, certain meanings will get lost.

Trusting the Outcomes of Digital Technologies

Algorithms were developed to enable machines to follow instructions. The human desire to delegate tasks to tools and machines can be traced back to the use of mechanical devices for calculation. This use dates back millennia: the Babylonians used clay tablets and counting boards for mathematical and astronomical problems, while Egyptians developed tools to predict the Nile's flooding (Ausiello, 2013; Grigoriadou, 2023). The nineteenth century brought significant changes in this evolutionary process for machines were built that could perform calculation tasks independently, rather than merely serving as tools. Initially, these tasks were simple, but in recent decades, digital technologies have taken on increasingly complex tasks through Artificial Intelligence (AI), with algorithms as instructions. The rise of algorithms must therefore be identified as a major discontinuity, and consequently as the second epitome technology in the evolution of digitalization.

In the evolutionary development of algorithms, multiple phases can be distinguished in which the pre-individual changed and humans deviated in their responsiveness to technological evolution. A significant early moment occurred in the seventeenth century, when Wilhelm Leibniz advanced calculating tools to the level of calculating machines, which could perform calculations independently instead of being a tool (O'Regan, 2021). Although he did not construct a fully functional model (Morar, 2015), the idea of an autonomous calculating machine was born.

In the nineteenth century, Ada Lovelace took the question of what can be achieved by machines to a new level by considering that they could perform tasks beyond calculations. Inspired by Charles Babbage's Analytical Engine—which used punch cards for input and memory, featured a printer for output, and included a primitive processor—Lovelace hypothesized that such a machine could be applied to scientific problems, generate graphics, and even compose music (Natale & Henrickson, 2024; O'Regan, 2021). However, she maintained that machines could not exceed the instructions they were given (Gonçalves, 2023; Heffernan, 2024). While Lovelace only designed the machine she envisioned, the idea that technologies could do more than just calculating was born.

In the 1930s, mathematicians had the mechanical computers with punch cards of the nineteenth century at their disposal. Their concern was not primarily about further developing of calculating machines, but to think about the limitations of mathematics. Alan Turing used existing calculating machines to consider these limitations (Millican, 2021) and that real numbers are computable (Gherardi, 2011). He described what is now known as the Turing machine to prove certain impossibilities of mathematics. Different from following instructions on a punch card, it read symbols on a paper and followed instructions of what to do with these symbols. These instructions could be replaced so that the machine could carry out various kinds of tasks. These stored instructions can be called algorithms (Copeland & Proudfoot, 2005). This paved the way for the development of digital technologies, that operate on the binary system of zeros and ones and receive their instructions from algorithms.

Since the spread of digital computers in various types (phone, tablet, smartwatch) into society, it has become increasingly self-evident that machines can perform all kinds of tasks. Today, it has become as self-evident that digital technologies can assume complex tasks that there is a growing trust in the outcomes they provide. A pedometer indicates whether enough steps have been taken; GPS navigation devices provide directions; and when a weather app predicts rain, people may hesitate to go outside even if the sky is clear. Tasks are not just assumed by digital technologies; their 'judgment' is often valued more than our personal judgment, making them part of our decision-making process.

A topic where our trust in digital technologies can be questioned is their assumed ability to mitigate climate change while maintaining welfare. While many such technologies show promise (Balogun et al., 2020), their sustainability remains questionable due to high energy consumption (Lannelongue et al., 2021). Despite this concern, there is widespread confidence that scientists and engineers will find ways to reconcile digitalization with environmental goals. Such examples illustrate that an important implication of our growing trust in digital technologies as the default way to understand and experience the world is that alternative solutions to problems and our own abilities risk being overlooked.

The next section will explore step 4–5 of the method outlined subSect. "Turning Simondon's Perspective into a Method", meaning whether the meta-physical structures and their implications found in Sect. "Digitalization in an Evolutionary Perspective" are also findable in precision farming.

Reflecting on Meta-Physical Structures in Precision Farming

In Sect. "Digitalization in an Evolutionary Perspective" demonstrated that digitalization is associated with two fundamental changes in meta-physical structures: standardization and the growing trust in digital technologies. Since these changes pertain to meta-physical structures, they are deeply embedded in our thinking and increasingly taken as self-evident. This raises the question of how such changes will affect farming, given that precision farming is the digitalization of agriculture. SubSect. "The Rise of Standardization and Trusting Technologies in Agriculture" will explore step 4 of the method outlined subSect. "Turning Simondon's Perspective into a Method" by describing how precision agriculture aligns with the evolutionary process of digitalization and how this alignment affects social structures. SubSect. "Changes in Meta-Physical Structures in Agriculture" will subsequently address step 5 of the proposed method, focusing on meta-physical structures in precision farming.

The Rise of Standardization and Trusting Technologies in Agriculture

Situating precision agriculture within the context of the meta-physical structures of the digital age, reveals its alignment with these structures. Changes in meta-physical structures that are associated with digitalization emerged well before the rise of actual digital technologies. Ideas related to standardization in farming can be traced back to the 1920s. For example, Linsley and Bauer (1929) proposed applying fertilizer only where needed, based on pH tests of soil samples. They outlined a systematic approach to mapping fields and determining precise lime application rates. Today, standardization is deeply embedded in farming practices, driven both by digital technologies and industrial norms. As standardization becomes increasingly self-evident to us, it permeates nearly all aspects of society, including agriculture and the industry.

Similarly, trust in the autonomous functioning of technologies in farming can also be traced back before the rise of actual digital technologies. The first fully mechanical tractor capable of plowing without human intervention was patented in 1941 (Andrew, 1941; Mulla & Khosla, 2015). Today, precision farming technologies increasingly assume complex tasks, such as monitoring animal welfare through camera systems (Guo et al., 2023; Putten et al., 2025).

Agriculture, therefore, is not exempt from these changes in meta-physical structures. When society in general was standardized and complex tasks were increasingly assumed by digital technologies, farming has followed the same trajectory. In Sect. "Digitalization in an Evolutionary Perspective", it showed that two implications arise when standardization and our growing trust in digital technologies become the default way to understand and experience the world: 1. The loss of meaning. 2. Losing sight of alternative solutions to problems and of our own abilities. Taken together, these implications suggest that the loss of meaning may go unnoticed precisely because of our trust in digital technologies.

Such concerns have already been raised in relation to sociological structures. It has been argued that the kind of information that does not fit digital technologies includes experiential and sensory knowledge—such as the feel or taste of a field (Carolan, 2020) or its aesthetic qualities (Schneider et al., 2010). Farming knowledge is not purely theoretical; it is embedded in practice and transmitted through social, embodied processes that require time and direct engagement. As farmers increasingly rely on digital platforms to assess their fields and animals, this embodied knowledge may erode (Brooks, 2021; Wilkie, 2010). Embodied knowledge also implies that there is not always a single optimal course of action in farming. Farmers often have personal preferences, (Aravindakshan et al., 2021; Shortall, 2024) which may conflict with the recommendations of precision technologies. As trust in digital systems grows, future farmers may increasingly defer to algorithmic instructions, sidelining their own judgment.

Another social concern arises from the way entities are observed through screens, since their differences may become less apparent. Unlike plants, animals possess feelings and intelligence. While farmer-animal interaction has already declined on large farms (Wernersson & Boonstra, 2024) further reliance on screen-based observation may reduce awareness of these distinctions. Through direct interaction, farmers develop the ability to sense how their animals feel (Acharya et al., 2022; Kling-Eveillard et al., 2020). As screen time replaces time spent with animals, emotional recognition may diminish.

Changes in Meta-Physical Structures in Agriculture

Concerns mentioned in subSect. "The Rise of Standardization and Trusting Technologies in Agriculture" all relate to the issue of the loss of meaning in sociological structures. Heidegger (1977) reflected on meta-physical structures and argued that modern technology is a way of revealing, which will lead to the loss of meaning. While the broader question of whether this applies to modern technology in general is beyond the scope of this paper, it does apply to precision farming. The mode of observation—whether through direct interaction or screen-based representation—shapes how agricultural assets are experienced and understood. When farmers rely solely on screens, various meanings will not be part of the representation, such as the crucial differences between plants and animals and the sensory information farmers derive from direct observation. Precision technologies thus reveal fields, plants, and animals as similar entities devoid of sensory richness.

This new mode of revealing contributes to path dependency in meta-physical structures. As Kay (2005) describes it:

> "A process is path dependent if initial moves in one direction elicit further moves in that same direction; in other words the order in which things happen affects how they happen; the trajectory of change up to a certain point constrains the trajectory after that point." (Kay, 2005, 553)

Path dependency can be found in the evolution of digitalization as described in Sect. "Digitalization in an Evolutionary Perspective". The ancient aims of long-distance communication and calculation tools evolved into efforts to standardize society and technologies assuming complex tasks. These shifts led to digital technologies that standardize the world into zeros and ones and guide the farmers' decision-making through screens. Alongside these sociotechnical changes, meta-physical structures also changed: as humas we started to experience the world differently, as standardization has become normal and we increasingly trust digital technologies to assume complex tasks.

The implications of these shifts in meta-physical structures are illustrated by the concept of the cyborg farmer—a farmer who combines digital insights with direct observation. This hybrid approach allows sensory experience, digital data, and embodied knowledge to complement one another in decision-making (Velden et al., 2024). However, when the farmer's experience and understanding fundamentally change, the problem is not so much that they do not observe their fields, plants, and animals by their own senses, but that in time they will not see the relevance of direct observation anymore. In the future, the cyborg farmer may be seen as an outdated compromise—akin to returning to the plough. Early signs of this shift are already visible: some North American farmers report diminished ability and trust in field assessment through direct observation (Carolan, 2020), while some French farmers consult data before visiting their animals and state that they not even believe in a human-animal relationship anymore (Kling-Eveillard et al., 2020).

The cyborg farmer may offer a temporary solution, but as Sect. "Digitalization in an Evolutionary Perspective" showed, we are moving toward a future where trust in digital systems overrides trust in human judgment. The challenge with changing meta-physical structures is their resistance to reversal. As farmers' experience and understanding of their environment fundamentally changes, the value of embodied knowledge passed down through generations may no longer be recognized.

Yet, this trajectory is not inevitable. Path dependency allows for choice (Kay, 2005). Additionally, concrete technologies can impact meta-physical structures (Blok, 2022a), just as the telegraph and algorithms have co-shaped how we experience and understand the world today. By making meta-physical structures explicit, their implications can be critically examined, allowing for reflection on how to mitigate potential negative outcomes—such as the loss of meaning in farming. This paper has proposed a method for such reflection and illustrated its relevance through the case study of precision agriculture.

Conclusion

Precision farming is currently being advanced by researchers and engineers with the aim of addressing global challenges such as feeding a growing population and mitigating climate change. While scholars have begun to reflect on both the promises and risks of precision farming in sociological structures, the meta-physical structures underlying these technologies—how the world is experienced and understood in a given era—have received comparatively little attention. This paper has aimed to develop a method for reflecting on meta-physical structures within the context of precision farming.

Drawing on Simondon's evolutionary perspective, the paper proposed a method that situates technologies within broader evolutionary developments. This approach highlights that technologies do not simply appear in history but are part of a larger evolutionary process involving other technologies, milieus, human desires, etc.

Simondon's framework also enables reflection on technological developments without relying on predetermined normative assumptions.

The proposed method consists of five steps:

Step 1. Identify the epitome technology
Step 2. Identify the pre-individual before and after the epitome technology
Step 3. Compare the pre-individuals and reflect on changes in understanding
Step 4. Identify the meta-physical structures in a concrete practice
Step 5. Reflect on changes in understanding in a concrete practice

To bridge the gap between the technological evolution based on Simondon's perspective and meta-physical reflection, two guiding questions were added to thematize what typically remains unthematized or self-evident:

A. In what ways does this fundamental change alter how things are experienced and understood?
B. What are the implications when this becomes the default way for experiencing and understanding things?

Since this method focuses on long-term evolutionary processes, it does not capture the meta-physical implications of concrete technologies. Addressing these implications will require additional steps beyond the five outlined here.

This method was applied in Sects. "Digitalization in an Evolutionary Perspective" and "Reflecting on Meta-Physical Structures in Precision Farming". Sect. "Digitalization in an Evolutionary Perspective" demonstrated that multiple epitome technologies can emerge within an evolutionary process. In the case of digitalization, the telegraph and algorithms were identified as epitome technologies, representing the societal shift toward standardization and the growing trust in digital outputs, respectively.

Sect. "Reflecting on Meta-Physical Structures in Precision Farming" reflected on meta-physical structures in precision agriculture, showing that its development aligns with the broader evolution of digitalization. As with digital technologies in general, early efforts to structure farming and develop autonomous machinery predate digital technologies. The analysis also revealed that not all forms of agricultural knowledge can be converted into the binary system of zeros and ones—particularly farmers' embodied knowledge. Moreover, the representation of plants and animals on screens tends to obscure their fundamental differences. If digital representations become the default mode of how agricultural assets are revealed to farmers, and if farmers lose trust in direct observation and embodied knowledge, the nature of farming will fundamentally change—resulting in a loss of meaning.

This loss of meaning occurs because precision technologies reveal agricultural assets in a particular way—one that may ultimately impoverish the richness of direct experience. Sect. "Digitalization in an Evolutionary Perspective" showed how digitalization has already reshaped our experience and understanding of the world, and Sect. "Reflecting on Meta-Physical Structures in Precision Farming" demonstrated that this transformation is already happening in agriculture. Since changes in how we experience and understand the world are very difficult to reverse—what is experienced as outdated is rarely reintroduced—there is a path dependency in the evolution of meta-physical structures.

It is therefore crucial to take meta-physical structures into account in reflections on the future of precision farming. Early intervention can help mitigate the loss of meaning and support the integration of precision technologies in a meaningful way. The method proposed in this paper is intended to support such reflection.

Declarations The author has no relevant financial or non-financial interests to disclose.

Data availability Not applicable.

References

Acharya, R. Y., Hemsworth, P. H., Coleman, G. J., & Kinder, J. E. (2022). The animal-human interface in farm animal production: Animal fear, stress, reproduction and welfare. *Animals, 12*, 487. https://doi.org/10.3390/ani12040487

Agrawal, G. P. (2016). Optical communication: its history and recent progress. In M. D. Al-Amri, M. M. El-Gomati, & M. S. Zubairy (Eds.), *Optics in Our Time* (pp. 177–199). Springer Nature. https://doi.org/10.1007/978-3-319-31903-2

Altmann, I. (2023). Gustav Theodor Fechner as natural scientist. *Chemtexts, 9*, 3. https://doi.org/10.1007/s40828-022-00174-1

Andrew, F. W. (1941). *Automatic tractor control* (United States Patent No. U. S. P. Office.

Aravindakshan, S., Krupnik, T. J., Amjath-Babu, T. S., Speelman, S., Tur-Cardona, J., Tittonell, P., & Groot, J. C. J. (2021). Quantifying farmers' preferences for cropping systems intensification: A choice experiment approach applied in coastal Bangladesh's risk prone farming systems. *Agricultural Systems*. https://doi.org/10.1016/j.agsy.2021.103069

Ausiello, G. (2013). Algorithms, an historical perspective. In G. A. R. Petreschi (Ed.), *The power of algorithms: Inspiration and examples in everyday life* (pp. 3–26). Springer-Verlag. https://doi.org/10.1007/978-3-642-39652-6__1

Ayres, R. (2016). Energy, complexity, and wealth maximization. *Springer*. https://doi.org/10.1007/978-3-319-30545-5

Balogun, A.-L., Marks, D., Sharma, R., Shekhar, H., Balmes, C., Maheng, D., Arshad, A., & Salehi, P. (2020). Assessing the potentials of digitalization as a tool for climate change adaptation and sustainable development in urban centres. *Sustainable Cities and Society, 53*, 101888. https://doi.org/10.1016/j.scs.2019.101888

Beluhova-Uzunova, R. P., & Dunchev, D. M. (2019). Precision farming–concepts and perspectives. *Problems of Agricultural Economics, 3*(360), 142–155. https://doi.org/10.30858/zer/112132

Bijker, W. E. (1995). *Of bicycles, bakelites, and bulbs: Toward a theory of sociotechnical change*. MIT Press Ltd.

Blok, V. (2022a). The ontology of technology beyond anthropocentrism and determinism: The role of technologies in the constitution of the (post)Anthropocene world. *Foundations of Science*. https://doi.org/10.1007/s10699-022-09829-1

Blok, V. (2022b). The role of human creativity in human-technology relations. *Philosophy & Technology, 35*(59), 19. https://doi.org/10.1007/s13347-022-00559-7

Blok, V. (2024). Ecological hermeneutic phenomenology as method to research the ontic and ontological structure of technologies in the world. In B. d. Boer & J. Zwier (Eds.), *Phenomenology and Philosophy of Technology* (pp. 27–51). OpenBookPublishers. https://doi.org/10.11647/OBP.0421#resources

Blok, V. (forthcoming). Technological innovation as ontogenetic process: critical engagements with Simondon's concept of technical evolution. In M. Coeckelbergh & M. T. Young (Eds.), *Process philosophy and technology: new directions*.

Borgmann, A. (1984). *Technology and the character of contemporary life*. The University of Chigago Press.

Brooks, S. (2021). Configuring the digital farmer: A nudge world in the making? *Economy and Society, 50*(3), 374–396. https://doi.org/10.1080/03085147.2021.1876984

Carey, J. W. (2018). Time, space, and the telegraph. In P. U. P. Heyer (Ed.), *Communication in History. Stone Age Symbols to Social Media* (7 ed., pp. 125–131). Routledge. https://doi.org/10.4324/9781315189840

Carolan, M. (2020). Acting like an algorithm: Digital farming platforms and the trajectories they (need not) lock-in. *Agriculture and Human Values, 37*, 1041–1053. https://doi.org/10.1007/s10460-020-10032-w

Chen, Y.-C., Chen, L.-W., & Chang, M.-Y. (2022). A design of an unmanned electric tractor platform. *Agriculture, 12*, 112. https://doi.org/10.3390/agriculture12010112

Copeland, J., & Proudfoot, D. (2005). Turing and the computer. In J. Copeland (Ed.), *Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to build the Modern Computer* (pp. 107–148). Oxford Academic. https://doi.org/10.1093/acprof:oso/9780198565932.003.0006f

Eason, C. M. (1916). The farm tractor. *Transactions–society of Automobile Engineers, 11*(2), 363–397.

Gherardi, G. (2011). Alan Turing and the foundations of computable analysis. *The Bulletin of Symbolic Logic, 17*(3), 394–430. https://doi.org/10.2178/bsl/1309952319

Gonçalves, B. (2023). Can machines think? The controversy that led to the Turing test. *AI and SocieTy, 38*, 2499–2509. https://doi.org/10.1007/s00146-021-01318-6

Grigoriadou, V. J. (2023). The precursors of scientific models in ancient Egypt, Mesopotamia, and ancient Greek world: A comparative study. *European Journal of Theoretical and Applied Sciences, 1*(4), 574–582.

Guo, Q., Sun, Y., Orsini, C., Bolhuis, J. E., Vlieg, J. d., Bijma, P., & With, P. H. N. d. (2023). Enhanced camera-based individual pig detection and tracking for smart pig farms. *Computers and Electronics in Agriculture* 211, 108009.

Heffernan, T. (2024). The imitation game, the "child machine", and the fathers of AI. *AI and SocieTy, 39*, 353–357. https://doi.org/10.1007/s00146-022-01512-0

Heidegger, M. (1977). *The question concerning technology and other essays* (W. Lovitt, Trans.). Garland Publishing inc.

Karunathilake, E. M. B. M., Le, A. T., Heo, S., Chung, Y. S., & Mansoor, S. (2023). The path to smart farming: Innovations and opportunities in precision agriculture. *Agriculture, 13*, 1593.

Kay, A. (2005). A critique of the use of path dependency in policy studies. *Public Administration, 83*(3), 553–571. https://doi.org/10.1111/j.0033-3298.2005.00462.x

Kling-Eveillard, F., Allain, C., Boivin, X., Courboulay, V., Créach, P., Philibertf, A., Ramonet, Y., & Hostiou, N. (2020). Farmers' representations of the effects of precision livestock farming on human-animal relationships. *Livestock Science*. https://doi.org/10.1016/j.livsci.2020.104057

Lannelongue, L., Grealey, J., & Inouye, M. (2021). Green algorithms: Quantifying the carbon footprint of computation. *Advanced Science, 8*, 2100707. https://doi.org/10.1002/advs.202100707

Lindberg, S. (2019). Being with technique-technique as being-with: The technological communities of Gilbert Simondon. *Continental Philosophy Review, 52*, 299–310. https://doi.org/10.1007/s11007-019-09466-9

Linsley, C. M., & Bauer, F. C. (1929). *Test your soil for acidity*. University of Illinois.

Macchi, G., & Pisapia, N. D. (2024). Virtual reality, face-to-face, and 2D video conferencing differently impact fatigue, creativity, flow, and decision-making in workplace dynamics. *Scientific Reports, 14*, 10260. https://doi.org/10.1038/s41598-024-60942-6

Millican, P. (2021). Alan turing and human-like intelligence. In S. M. N. Charter (Ed.), *Human like machine intelligence* (pp. 24–51). Oxford University Pres. https://doi.org/10.1093/oso/9780198862536.003.0002

Monteiro, A., Santos, S., & Gonçalves, P. (2021). Precision agriculture for crop and livestock farming—brief review. *Animals, 11*, 2345.

Morar, F.-S. (2015). Reinventing machines: The transmission history of the Leibniz calculator. *The British Journal for the History of Science, 48*(1), 123–146. https://doi.org/10.1017/S0007087414000429

Mulla, D., & Khosla, R. (2015). Historical evolution and recent advances in precision farming. In R. Lai & B. A. Steward (Eds.), *Soil-Specific Farming* (pp. 1–36). CRC Press. https://doi.org/10.1201/b18759-2

Müller-Pohl, S. (2010). "By Atlantic Telegraph" A Study on Weltcommunication1 in the 19th Century. Medien & Zeit Kommunikation in Vergangenheit und Gegenwart(4), 40–54

Natale, S., & Henrickson, L. (2024). The lovelace effect: Perceptions of creativity in machines. *New Media & Society, 26*(4), 1909–1926. https://doi.org/10.1177/14614448221077278

O'Regan, G. (2018). *The innovation in computing companion. a compendium of select, pivotal inventions*. Springer. https://doi.org/10.1007/978-3-030-02619-6

O'Regan, G. (2021). *A brief history of computing* (3 ed.). Springer. https://doi.org/10.1007/978-3-030-66599-9

Putten, Av., Giersberg, M. F., & Rodenburg, T. B. (2025). Tracking laying hens with ArUco marker backpacks. *Smart Agricultural Technology, 10*, 100703. https://doi.org/10.1016/j.atech.2024.100703

Rikitianskaia, M., & Balbi, G. (2021). What time is it? History and typology of time signals from the telegraph to the digital. *International Journal of Communication, 15*, 1513–1530.

Rose, P. S. (1915). Farm tractors and their engines. *Transactions (Society of Automobile Engineers), 10*(2), 257–276.

Schneider, F., Ledermann, T., Fry, P., & Rist, S. (2010). Soil conservation in Swiss agriculture—Approaching abstract and symbolic meanings in farmers' life-worlds. *Land Use Policy, 27*, 332–339. https://doi.org/10.1016/j.landusepol.2009.04.007

Shortall, O. (2024). Should cows graze? A relational approach to understanding farmer perspectives on the ethics of grazing and indoor dairy systems. *Sociologia Ruralis, 64*, 531–551. https://doi.org/10.1111/soru.12487

Simondon, G. (2017). *On the mode of existence of technical objects* [Du mode d'existence des objets techniques] (C. Malaspina & J. Rogove, Trans.). Univocal Publishing. (1958)

Simondon, G. (2020). *Individuation in light of notions of form and information* [L'individuation à la lumière des notions de forme et d'information] (T. Adkins, Trans.; Vol. 57). University of Minnesota Press.

Souza, J. D., Gillett, K., Salifu, Y., & Walshe, C. (2024). Changes in participant interactions. Using focus group analysis methodology to explore the impact on participant interactions of face-to-face versus online video data collection methods. *International Journal of Qualitative Methods, 23*, 1–14. https://doi.org/10.1177/16094069241241151

Velden, D., Klerkx, L., Dessein, J., & Debruyne, L. (2024). Cyborg farmers: Embodied understandings of precision agriculture. *Sociologia Ruralis, 64*, 3–21. https://doi.org/10.1111/soru.12456

Wernersson, H. C., & Boonstra, W. J. (2024). Making meat moral: A comparison of rearing and killing practices in Swedish cattle farming. *Sociologia Ruralis, 64*, 254–279. https://doi.org/10.1111/soru.12472

Wheen, A. (2011). *Dot-Dash to Dot.Com. How modern telecommunications evolved from the telegraph to the Internet*. Springer and Praxis Publishing. https://doi.org/10.1007/978-1-4419-6760-2

Wilkie, R. M. (2010). *Livestock/Deadstock: Working with farm animals from birth to slaughter*. Temple University Express.

Zerubave, E. (1982). The standardizationof time: A sociohistorical perspective. *American Journal of Sociology, 88*(1), 1–23.