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Review

Designing with non-humans for agricultural systems transformation: An interdisciplinary review and framework for reflection

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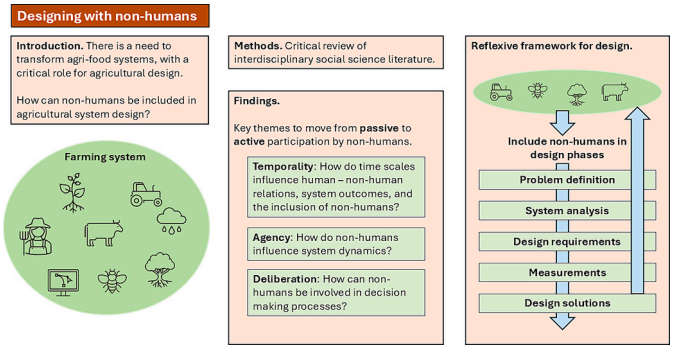
HIGHLIGHTS

- Agriculture must move beyond anthropocentrism to tackle socio-ecological crises.
- Participatory design is increasingly used to foster democratic systems design.
- Non-humans are largely overlooked in participatory agricultural design processes.
- Critical social sciences offer insights for fostering transformative systems design.
- We propose practical interventions to better integrate non-humans in systems design.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: In response to growing concern over agriculture's contribution to climate and ecological crises, recent definitions of sustainable food systems have expanded beyond productivity to emphasize interconnected ecological and social dimensions. Responding to this challenge, agricultural system design scholars have moved beyond a focus on merely increasing productivity, supply, and profitability, to include goals such as animal welfare and ecological health. However, this selection often fails to move beyond anthropocentric needs and values. For design to be transformative, addressing who can participate in design and how participating actors relate to each other is critical. Notably, non-humans, which are foundational to agricultural systems, are largely overlooked as actors to be involved in design processes.
OBJECTIVE: The aim of the article is to develop a framework to assist agricultural design scholars in meaningfully integrating non-human needs in agricultural design processes by identifying and reflecting upon trade-

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Posthuman design
Bioeconomy

offs and providing methodological tools with the goal of contributing to just and sustainable transformations of agricultural systems.
METHODS: A critical review of the state-of-the-art of non-human participation in agricultural systems design research was done. This was followed by a narrative review, consulting several approaches from critical social sciences, such as transition studies, Actor Network Theory, animal studies, feminist posthumanism, post-colonialism and indigenous scholarship to enhance our understanding of participation by non-humans. This analysis informed a synthesized framework for reflection.
RESULTS AND CONCLUSIONS: The review points at three themes for better engagement of non-humans in design, notably regarding the role of (1) agency; (2) temporality; and (3) deliberation of non-humans. Based on these themes, practical steps forward are proposed to include non-humans in five design phases: problem definition; system analysis; design requirements; measurements; and selecting design solutions.
SIGNIFICANCE: By opening a dialogue between agricultural systems design and different bodies of research on inclusion of non-humans, this article aims to support agricultural systems designers in their reflection, making informed, context-sensitive decisions by fostering new ways of thinking and relating to non-humans as active rather than passive actors in these processes, thereby enhancing the transformative potential of agricultural systems research and design beyond anthropocentric perspectives.

1. Introduction

In response to growing concern over agriculture's contribution to climate and ecological crises (Campbell et al., 2017), recent definitions of sustainable food systems have expanded beyond productivity to emphasize interconnected ecological and social dimensions (FAO, F, 2018; Rockström et al., 2020). For agricultural systems, as a crucial part of food systems, to be considered sustainable, they must now simultaneously address climate adaptation and mitigation, ecosystem and soil restoration, biodiversity conservation, nutritious food production, poverty eradication, resilience enhancement, inequality reduction, and promotion of political stability (Çakmakçı et al., 2023), in order to promote health and wellbeing of farmers, consumers, and the planet as a whole. These broad understandings of sustainable agriculture recognize that agriculture's enormous ecological, social, and economic influence must be leveraged to integrate a broad set of goals rather than prioritizing supply for affluent human populations (Caron et al., 2018; Tribaldos and Kortetmäki, 2022).

Agricultural systems design plays an important role in shaping agricultural and hence food system outcomes and therefore bears substantial responsibility for creating systems aligned with comprehensive sustainability goals. Responding to this challenge, design scholars have moved beyond a focus on merely increasing supply, production, and profitability (Martin et al., 2013). Participatory design has emerged in design scholarship as a process that increasingly incorporates diverse stakeholders and marginalized groups throughout the design stages, with the intention of yielding outcomes that are more integrated, effective, and just (Huttunen et al., 2022; Robertson and Simonsen, 2012; Martin et al., 2013; Cerf et al., 2012). Building on the work in participatory design, a growing body of scholarship argues that to meet comprehensive sustainability goals we must extend participation beyond humans. Various scholars have called for acknowledging a wider range of values, stakes, and interests, highlighting the need to actively address the stakes of non-humans within participatory processes in agriculture (Bastian, 2017; de Bruin et al., 2024; Kok and Klerkx, 2023; Nicenboim et al., 2024; Tschersich and Kok, 2022).

An interdisciplinary body of work is therefore developing concepts and methodologies to meaningfully include non-humans in agricultural system transitions and design. Examples include recent extensions of the Agricultural Innovation Systems approach (Pigford et al., 2018; Plummer et al., 2024) and work on sustainability transitions in agricultural systems (Contesse et al., 2021; Vermunt et al., 2020), where non-humans are now considered as participants in innovation processes next to humans, and Reflexive Interactive Design (Bos and Grin, 2008; Romera et al., 2020), where non-humans are considered stakeholders with needs in the design process. Within this lineage of work, two recurring challenges have emerged. First, agricultural systems inherently present tradeoffs between goals, including between human and non-human needs and interests, as these systems fundamentally intervene in food webs where life, death, consumption, and ecological processes are intertwined. Second, despite efforts to incorporate natural actors in design processes, both methodological and conceptual tools remain limited for including non-humans as meaningful participants. Particularly integrating non-human considerations beyond anthropocentric ideals and utilitarian lenses has been less conceptualized so far. Even within nature-inclusive agriculture frameworks, conventional productivity aims often remain the standard to which nature must accommodate (Runhaar, 2017). While non-humans are the foundation of agricultural systems, they remain largely overlooked as actors to be meaningfully and dynamically involved in design processes (Pigford et al., 2018). Such superficial engagement with goals beyond production may mitigate damage but risks reinforcing and prolonging conventional agricultural paradigms (Kothari et al., 2014).

We recognize that agricultural systems will always present tradeoffs between human and non-human needs and interests. However, we contend that the overlooked non-human element of agricultural systems design (ASD) is a critical aspect for more effective agri-food transitions that meet comprehensive sustainability goals. In view of this gap, this article develops a framework to assist agricultural design scholars in identifying and reflecting upon trade-offs and to provide methodological tools to engage with natural entities and meaningfully integrate non-human needs in agricultural design processes. To do so, we consult disciplines which have further developed on the theme of more-than-human inclusion, including transition studies, Actor Network Theory, animal studies, feminist posthumanism, postcolonialism and indigenous scholarship. These disciplines have developed diverse and complementary theory-based practices to meaningfully engage with natural entities.

Our article continues as follows. After explaining our methods in Section 2, in Section 3 we provide a brief interdisciplinary state-of-the-art review of non-human inclusion in agricultural design processes. Next, in Section 4 we introduce concepts and methodological tools to foster engagement with and by non-humans. Then, in Section 5 we present a reflective framework to assist agricultural systems designers in better participating with non-humans based on five design phases (problem definition, system analysis, design requirements, measurement practices, design solutions). We conclude by critically discussing the framework's utility for integrated sustainability and its limitations and propose questions for further research.

2. Definition and methods

2.1. Non-human working definition

Non-humans can be defined broadly to include any being or entity that is not human, whether it be animals, plants, ecosystems, water

bodies, tools, or systems like the economy. We conceptualize non-humans on a continuum, from natural to human-made (Fig. 1).

On one side of the spectrum, for example, there might be a wild animal and at the other end a tractor, with a whole range of actors in between. While it is beyond the scope of the article to engage with debates over artificiality and human-nature binaries here, for the purposes of this article it is helpful to reflect on the extent of human intervention in the creation of non-humans. There is a long tradition of research on the role of human-made materials in agriculture (such as machinery or artificial fertilizers) and how they shape and co-evolve with agricultural systems (Glover, 2022; Jansen and Vellema, 2011; Rosin et al., 2017) and through actual use by farmers, in processes which have been referred to as 'innofusion' (Fleck, 1993) and 'coupled innovation' (Salembier et al., 2020). Many non-humans in agricultural systems are somewhere in between the two ends of the continuum, for example crops are both naturally occurring, yet also commonly genetically bred by humans. This notion of artificiality of nature in farming was already noted in 1969 by Herbert Simon (Simon, 1996), who wrote in his seminal work 'The sciences of the artificial' that "A forest may be a phenomenon of nature; a farm certainly is not. The very species upon which we depend for our food our corn and our cattle are artifacts of our ingenuity" (Simon, 1996: 3). This debate on the boundaries between naturalness and artificiality has been given a new twist with reflections on the agency of autonomous technologies such as Artificial Intelligence and Digital Twins in the sense that they aim to fully mimic the natural world and take over agency from the farmer (Geiselmann et al., 2023; Higgins et al., 2017; Pylianidis et al., 2021; Ryan, 2023; Verdouw et al., 2021). As philosophers have argued, hybrids between humans, natural non-humans and technologies, are becoming a new ontological category (Blok and Gremmen, 2018; Holy-Luczaj and Blok, 2021; Forlano, 2017; Korenhof et al., 2021), and some have empirically studied in the case of precision agriculture what they refer to as 'cyborg animals' and 'cyborg farmers' (Søraa and Vik, 2021; Van der Velden et al., 2024).

2.2. Methods

A critical review format was followed to critically analyze the state-of-the art in non-human participation in ASD for Section 3. This format allows for highlighting strengths and weaknesses in the literature without performing an exhaustive review (Paré and Kitsiou, 2017). To move beyond the state-of-the-art and broaden the scope on non-human participation in ASD, a narrative review approach was followed for Section 4, as we aimed to identify what has been written on non-human participation in a variety of disciplines of relevance to, but not yet considered to a large degree, in ASD and identify common narratives (Paré and Kitsiou, 2017). Through our narrative review we identified emerging themes and assessed the uptake of the concept of non-human participation in various critical social science fields such as science and technology studies, transition studies, and indigenous scholarship with relevance to the field of agriculture and the potential to inform ASD, which have also figured in other reviews of non-human participation in design (Forlano, 2017). See also Appendix A: Supplementary materials, in which a deeper elaboration is provided of these different fields.

Google Scholar was used to find a broader range of literature, both peer-reviewed and grey literature. For the state-of-the-art (Section 3) the following search terms were used, informed by the authors' knowledge of the field: "design" OR "co-design" OR "re-design" AND "farming"; "agriculture"; "agricultural systems"; "participatory"; "participation"; "more-than-human"; "posthumanism"; "non-humans". To identify relevant literature outside of ASD (Section 4) the following search terms were used, informed by the authors' transdisciplinary knowledge across disciplines: "more-than-human" OR "non-humans" AND "participatory"; "participation"; "communication"; "deliberation"; "temporality"; "agency"; "design"; "ANT"; "MLP"; "decolonial"; "indigenous"; "care"; "feminist"; "posthumanism"; "materialism"; "relational"; "sustainability transitions". A snowballing method was also used, finding articles through citations in articles that came up in our search and through special issues that came up in our search. One complementary interview was held with Gabriela de la Rosa, an academic studying transdisciplinary participatory research methods, to deepen our understanding of a method to include non-humans in human decision-making processes. Additionally, works on the topic already known to the authorship were included, resulting in a multidisciplinary approach with author backgrounds in sustainability transitions, participatory design, agronomy, agroecology, feminist posthumanism, sociology, and political ecology.

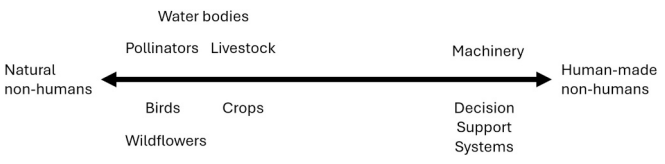

Fig. 1. Natural - human-made non-human continuum.

Both peer-reviewed and grey literature were included. Searches were performed in English, thus only English-written material was included. There was no time range set in the search due to the emergent nature of the topic. Abstracts were screened for relevance to the review before reading full texts. If non-humans were not addressed in the research (directly or indirectly), the text was not included. This review was done iteratively; themes were identified through the process of reading and analyzing literature, and the continuation of the search was informed by the insights found in the review process.

While the selected disciplines have divergent backgrounds and underpinnings, we take a crosscutting approach to examine how different perspectives, disciplines, and knowledge traditions interfere with one another to generate novel patterns of understanding. Moreover, because all authors are from Western backgrounds, we explicitly sought to include scholarship from non-Western scholars and build on non-Western epistemologies during the review process to counter potential Western-oriented biases.

3. Current participation of non-humans in agricultural systems design

3.1. The distinction between material and representational participation of non-humans

Participatory design approaches have gained traction in ASD to foster more democratic, transformative, and societally relevant design, as they engage stakeholders in consultation and knowledge co-production processes. Since stakeholders tend to diverge in interests, participatory processes also encourage negotiations between sectors and different stakeholder groups, for example on what issue is at stake, the nature of the problem, and the solution directions (Leeuwis, 1999, 2000). In ASD, these include approaches such as participatory design of decision support and systems analysis tools (Carberry et al., 2002; Cerf et al., 2012; Martin et al., 2011; Ditzler et al., 2018; Rose et al., 2016), agricultural production systems design and re-design (Brun et al., 2021; Dogliotti et al., 2004; Kropff et al., 2001; Le Gal et al., 2011; Romera et al., 2020) and design of agri-food system transitions and innovation ecosystems (Meynard et al., 2017; Steinke et al., 2022; Wolfert et al., 2023).

Participatory design approaches generally involve actors such as farmers, government officials, and private sector companies, and these are believed to enhance applicability and ownership of the proposed design, increasing adoption and use, and have also been seen to better forecast and anticipate potential social effects of food system changes (Berthet et al., 2018; Elzen and Bos, 2019; Steinke et al., 2022). However, participatory processes are not without conflict and struggle: they are inherently political, and can reinforce power imbalances amongst

participants, not least of all through top-down decisions about who can participate and how (Barnaud et al., 2010; Tschersich and Kok, 2022; Turnhout, 2024). Such power imbalances jeopardize the democratic potential of participation, as these processes tend to exclude issues or actors that threaten the goals of the participatory process or those leading it (Meesters, 2023). This, we believe, also has implications for the inclusion of non-humans in participatory design.

In this subsection, we review the ways in which non-humans have been considered in participatory agricultural systems design so far. Agricultural design frameworks already include non-human considerations when they determine the best conditions to grow crops and animals to ensure food production or to enhance, streamline, or simplify production processes from an agronomist, productivist perspective (Gerber and Hiernaux, 2022; Grahmann et al., 2024; Pelzer et al., 2020; Reckling et al., 2020). The process in which distinct needs are accommodated (or not), including those of plants, animals, machinery, and soil, can be seen as a material form of participation. Following ideas on agency of non-humans (Latour, 2007), material objects, plants, infrastructures, and animals can be seen to co-shape physical reality in a process that can be described as a negotiation between various humans and nonhumans (Marres and Lezaun, 2011; Barry, 2013; Higgins et al., 2017, 2023), challenging that such negotiation only happens between human actors as commonly proposed (Leeuwis, 2000). Non-humans communicate about their needs in physical ways: through how they grow and reproduce, the colors of their leaves, whether they accommodate other forms of life, or by becoming rusty or failing to work in the case of machinery. Farmers are implicated in this negotiation when they attend to the needs of crops, animals, and machinery, and by adjusting situations to ensure crops, animals, and machinery thrive in specific ways. Such direct, bio-physical participation from non-humans thus shapes agricultural systems in the place where the non-humans reside and exert influence, a form of participation which we henceforth refer to as material participation. This material participation is a continuous and always occurring process, currently predominantly shaped by productivist goals, which limits how non-human participation can unfold.

Besides material participation, ASD increasingly draws on representational approaches to broaden the set of actors involved in design decisions. Representation most commonly occurs in co-design strategies, in which agricultural experts (i.e. farmers, consultants, and scientists), public officials, and local stakeholders (Berthet et al., 2016) who represent the interests and needs of other actor groups who are not directly included in the co-design process, including plants, animals, and machinery (i.e. veterinarians communicating the needs of a dairy cow through their expert knowledge). While representational processes tend to enlarge the set of actors and relationships that can influence agricultural system design, and these processes can, at times, lead to increased understanding of and interest in each (human) groups' needs (Turnhout et al., 2020), we notice that the non-humans in these relations are not generally considered as having agency per se, nor that their interests are meaningfully considered as part of the processes. Within representational participatory processes, non-humans are often considered rather passively, either as background conditions or as objects of production that can be adjusted at hand to conform to productivist interests (Meesters, 2023). Ultimately, they are either rendered as a collection of parts that can be optimized and controlled, or as uncontrollable conditions like the weather. Therefore, we contend that the goal of both the negotiation of interests and the subjectification of non-humans matters: most of these processes are geared towards maximized production while the interests in non-human flourishing and prosperity are not taken into account.

Nevertheless, some notable exceptions exist that work towards designing agricultural systems for transformative change and just outcomes which more actively consider non-humans, which we will discuss in the next subsection. We follow the distinction between the earlier defined material approaches, which point to physical negotiations between and amongst humans and non-humans in fields, stables, and forests (Meesters, 2023), and representational approaches, which are characterized by human or technological representation for non-human needs in the design process (e.g. scientist, farmer, or model). Before discussing these approaches to non-human inclusion in ASD, it is important to stipulate that rather than defining an end goal (e.g. more-than-human justice, environmental sustainability), we present various approaches that steer towards acknowledging complexity and considering the interests of non-humans, while they may differ in their formulation and conceptualization of goals.

3.2. *Examples of material and representational participation of non-humans in ASD*

Representational approaches are commonly found in the literature on non-human participation in ASD, such as case studies using methods like the Reflexive Interactive Design approach (RIO) or the Describe Explain Explore Design approach (DEED), to represent livestock and crops (Moreira et al., 2023; Puente-Rodríguez et al., 2019; Romera et al., 2020; van Weeghel et al., 2021), via various human experts that speak on their behalf. Through setting design requirements, some studies have incorporated the needs of non-humans in the design process, including those of crops (Moreira et al., 2023), cows (Romera et al., 2020), laying hens (van Weeghel et al., 2016), and environments more generally (Kanter et al., 2016; Prost et al., 2018; Quinio et al., 2022; Romera et al., 2020; van Weeghel et al., 2016). Others address non-human interests through design objectives, including those of biodiversity (Juventia et al., 2022; Quinio et al., 2022) or water bodies (Murgue et al., 2015; Quinio et al., 2022). Quinio et al. (2022) utilized design-support tools to help participants visualize the object of design, for example cards to represent mycorrhizal networks that the participants had to keep alive and consider how different design choices would affect their mycorrhizal network. They also defined design goals with requirements, i.e. develop mycorrhizal networks, or a maximum threshold for nitrate concentrations. Building on DEED, Juventia et al. (2022) propose a framework for spatio-temporal arable field design which incorporates farmers' dreams and objectives alongside mechanical constraints and ecological interactions as decision criteria for field designs. They explicitly weighed design options to diversify crops based on how well they facilitate desirable ecological relations, e.g. pest-natural enemy interactions or soil rest vs. disturbance, although the value of these ecological outcomes is largely evaluated from an anthropocentric perspective (ecosystem services).

We also found material approaches that took it a step further, presenting ways to actively participate with non-humans by fostering more complex, horizontal, and affective relations between humans and non-humans in agricultural systems. Ditzler and Driessen (2022) explored the design of automated tools for agroecological farming systems, asking what "might come out when various actors considered automation and designed tools specifically for an agroecological paradigm in which complexity is embraced, ecological cycles are fostered, and the boundaries between binaries such as crop/weed and labor/fulfillment are blurred" (p. 25). They engaged with a variety of human actors to explore this question, including farmers, technology developers, scientists, and designers. While they did not explicitly engage with non-humans as actors, they demonstrated that to wholly adopt an agroecological perspective (i.e., nature-based, socio-ecologically just) on farming systems design, entangled relations between humans and non-humans (including machines) must be considered as central to the design process, as others have also argued looking at design of harvesting robots (Legun et al., 2023).

Several articles referred to "conversations" or "dialogues" between designers and objects of designs. Cerf et al. (2012) argue for the importance of considering the 'use situation' in the design of decision support tools, describing a dialogue between humans, tools, and their use situations. Prost et al. (2018) describe an iterative process to the implementation of design concepts, citing an ongoing "conversation"

between the farm (and the non-humans within it) and the designers (the farmers and researchers). When solutions did not result in anticipated outcomes, the design was altered accordingly, which they refer to as 'adaptive management'. Quinio et al. (2022) identified negotiations between the farmer and the farm in the design process, for example organizing tilling around when thistle roots are least developed and sowing rapeseed earlier in the season so that the crop is strong enough to withstand insects in the fall. They reflected on the interaction between the designers and the tools and how the tools afforded knowledge sharing. They found that visual tools used to represent objects of design were useful for allowing designers to better understand the object and the consequences of design solutions for the object, resulting in a "reflective conversation" with the representation.

Another interesting way of considering non-humans in ASD can be found in the studies using the notion of "nature inclusive" design, even if it comes with challenges and conflicts. Nature-inclusive design, as a concept and policy priority, has generated tools for centering non-humans and multi-species approaches in systems design, especially in urban design (Gualtieri et al., 2023). It has largely focused on the incorporation of non-human species habitats in human occupied spaces (Sella et al., 2022) and advancing a more-than-human approach to consider multi-species relations in making design choices. For example, some insects may be seen as pests by humans but are essential to the vitality of other species who depend on them for food (Gualtieri et al., 2023). In farming, the language of nature-inclusive agriculture has gained significant traction, but also leads to challenges and conflicts. The title 'nature-inclusive' itself implies that nature and agriculture are separate entities, potentially perpetuating a binary view of non-humans as inferior to humans and human enterprises (Merchant, 2006). Its resonance with historical bifurcations between production and conservation means habitats for species are cultivated alongside productive spaces, and production choices that harm species are discouraged, but a more integrated approach remains politically and economically challenging (Runhaar, 2017; Vermunt et al., 2022).

Perhaps the most embodied design method in ASD that builds on place-based material non-human participation is permaculture design. Permaculture is an integrative, systems-thinking framework and method for ASD that is based on respecting and integrating the relational and intrinsic qualities of plants and animals to stimulate nature-based approaches to farming (Ferguson and Lovell, 2014). Permaculture design methods leverage natural ways in which plants relate, for instance by working on natural tendencies of plants to cover the soil, use all the available sunlight, and make efficient use of water (Ferguson and Lovell, 2014; Roux-Rosier et al., 2018). These methods can be called participatory because they work with non-humans' inclinations to determine what systems can work in specific localities (cf. Meijer, 2019). In other words, permaculture stimulates embodied, material negotiations between humans and their goals and needs (i.e. food production, aesthetics), and non-human needs and preferences (i.e. water, perenniality, genetic diversity). This differs from other design approaches because permaculture claims to work *with* non-humans (to a certain degree), by giving space to non-human agency, instead of imposing control over plants, animals. The main differences in this approach, then, are a challenge to the human – nature binary, a different conceptualization of agency, and adjusted power relations between humans and non-humans (Ferguson and Lovell, 2014; Roux-Rosier et al., 2018).

To build on previous work on participation in ASD, the following section draws on insights from other disciplines that have advanced both theoretically and practically in more-than-human inclusion, to critically analyze the current state of non-human participation in ASD.

4. Interdisciplinary insights on active participation of non-humans

While much has been done to bring participation, including representation of non-humans, to ASD, we look to bring insights from the critical social sciences to further the transformative potential of the field. The critical social sciences facilitate transformative change in sustainability transitions by politicizing and pluralizing debates and supporting structural and transformative system change, offering valuable insights (Massarella et al., 2021). Specifically, we look to disciplines that have advanced theoretically and practically on more-than-human inclusion. While non-humans are often considered passively in ASD, we argue that involving them more actively could lead to more transformative outcomes.

We draw on concepts and approaches that are developed in various fields, including work informed by transition studies, Actor Network Theory, animal studies, feminist posthumanism, postcolonialism and indigenous scholarship.[1] We do not aim to give a comprehensive overview of these fields nor contend that each field is neatly separated or fits into one fixed box. Instead, we draw on concepts and conceptual interpretations that we find benefit the scope of this article. We identified the themes of **agency, temporality, and deliberation** as running threads in this literature and will follow these threads through the rest of the article. For a deeper elaboration on the concepts considered, see the Supplementary materials in Appendix A.

To explore the first theme, agency, we engaged with approaches that recognize the active role of non-humans in shaping the world, through either concepts, theoretical perspectives or methodologies. While conceptualizations and implications differ, this work considers non-humans as influential and active participants in social, ecological, and technological systems, which challenges earlier deterministic and anthropocentric approaches. These approaches move, in more or lesser extent, away from the idea that non-humans are conditions or material foundations that influence social (i.e. human) processes and change, towards an understanding of non-humans as agentic bodies that engage in activities and relations. Non-humans including pests, diseases, soils, animals, waters, plants, and machines are increasingly considered to actively co-produce reality with other non-humans as well as with human beings (Campbell, 2020; Contesse et al., 2021; Legun, 2015a,b; Rosin et al., 2017). For human-made non-humans such as technology and machines, agency is shaped both by the intentions, assumptions, and biases of their human creators, reproducing the intentions, assumptions and biases of their human creators and by its societal uptake and reproduction (Latour, 1992), in which users also exercise agency and can greatly exceed or deviate from what the designers originally intended (Glover, 2022; Jansen and Vellema, 2011; Rosin et al., 2017).

The second theme we identified as a common thread amongst literature considering non-humans is temporality. Amongst a wide range of theoretical approaches, we identified a common critique of the dominant linear, human-centered, productivist conception of time that prioritizes efficiency and in which conventional design practices are often rooted (Bessai et al., 2024; Puig de la Bellacasa, 2015). These varying views share a critique of the hegemonic human-centered time scales we work in and recognize the imbalances this creates between humans and non-humans. Thus, involving non-humans could include involving non-

[1] As western raised and trained white scholars and in the context of this article, we can neither do justice to the depth and breadth of Indigenous bodies of work, nor respectfully place it in the colonial histories of violence and displacement in which western and indigenous knowledge are entangled (cf. Watts, 2016). Nevertheless, we would like to take up Kimmerer's (2013) suggestion that indigenous scholarship can help to inspire also non-indigenous scholars towards ways to build more-than-human societies (p. 9), and that engagement is needed to dialogue between epistemic worlds (Sundberg, 2014). For ethical engagement, we look to the concept of 'Ethical Space' by Ermine (2007), which highlights the importance of indigenous self-determination, mutual respect between different knowledge systems, and addressing power imbalances. In this article, we aspire to learn from and communicate about this important scholarship, without reinforcing colonialist appropriation, by encouraging scholars to be sensitive to place-based histories, different knowledge systems, and more-than-human presences.

human timescales, rather than imposing human timescales on non-humans. For participatory design, this means re-focusing and re-imagining the timescales of design projects can aid in fostering more inclusive participatory processes (Pschetz et al., 2024).

The third theme we identified was deliberation. Deliberative processes traditionally emphasize human participation and the use of logic and reason to reach collective decisions.[2] Such human qualities have been recently criticized, leading towards other types of models and practices that allow for including non-humans in deliberative processes. While many scholars share a recognition of the need to involve non-humans in deliberative processes, they differ in their views on the extent and methods. Some scholarship focuses on the ways in which non-humans already deliberate materially, with humans and other non-humans, while others consider how to further involve non-humans in discursive, democratic, political processes, mirroring the focus on material and representational processes. In our discussion below, we include both types of deliberation to showcase a variety of methods that may suit a range of ASD applications.

We argue that addressing the themes of agency, temporality, and deliberation with an interdisciplinary lens can foster better participation by non-humans in design processes. In the next section we elaborate further on how to engage with these themes in the context of participatory ASD and conclude with a framework for reflection.

5. A framework for reflection to better include non-humans in design processes

In this section we offer practical interventions for better inclusion of non-humans in various phases within a design process, considering the themes of agency, temporality, and deliberation. Design approaches differ in how design phases are defined and organized (Cerf et al., 2012; Kropff et al., 2001; Martin et al., 2013; Meynard et al., 2017; Prost, 2021), and in ASD scholarship several genealogies of design reasoning can be identified (Salembier et al., 2018). Here we focus on a generalized approach that draws heavily on the RIO methodology (Bos et al., 2009; Elzen and Bos, 2019): problem definition, system analysis, design requirements, measurement practices, and design concept. While we have organized this section in a linear way, we do not mean to convey that design processes should be linear, especially when including non-humans. Design processes should be reflexive, iterative, and flexible if they wish to involve non-humans as actors, as they require the ability to respond to unpredictable or unexpected expressions of agency and outcomes of interconnections (Hoppe, 2019). Additionally, inherent to the literature we have reviewed for this article, these insights are not meant to provide ready-to-use tools that can be applied in any context. Our understanding of practicality is not about delivering a framework or solutions that shift decision-making and ethical considerations away from designers. Rather, we seek to support agricultural systems designers in their reflection, making informed, context-sensitive decisions by fostering new ways of thinking and relating to non-humans. In this section we provide relevant examples of concepts used in practice, per highlighted design phase, to guide designers looking to implement these concepts. While many of the concepts addressed are versatile and can be applied across multiple design phases, we highlight them at the phases they are most relevant with practical examples. Table 1 presents a framework for reflection for researchers and designers that highlights the key findings from this section and offers guiding questions to address the themes of agency, temporality, and deliberation at each explored design phase. In what follows, we will further explain the framework.

5.1. Problem definition and design objectives

The problem definition and design objectives are foundational to a design process and therefore this is a critical phase to reflect on how non-humans are considered. Inherent to design objectives are underlying problem definitions. For example, imagine a system where weeds are a persistent barrier to yield (problem definition). The objective might be to improve crop production. Based on the literature we consulted, it is important to pause and consider our worldview, words, and concepts that form problem definition and objectives. Continuing with our example, how has the objective of production been defined in such a way that it defines other plants as weeds and barriers to that objective? How has a monoculture model of agriculture cultivated weeds, figuratively and literally? How does using the term 'weed' color our experience of a plant, and restrict the potential design solutions to a crop-weed conflict? Can we reframe viewing certain species as problems, to recognizing their role within an ecosystem?

By pausing and reflecting on questions regarding problem definition and design objectives, designers can consider and open up what it means to involve both human and non-humans as participants and deliberators during this phase of design. This resembles processes in which farmers are involved in defining goals for their own wellbeing. In an effort to design a farming system with improved animal welfare, van Veen and Helvoirt (2024) exemplify how to use a citizen assembly to negotiate or deliberate with dairy cows over design choices. In this case they used human actors as proxies for the cows; other representational approaches such as personas can also be used to include non-human voices in deliberative processes when discussing the problem definition, design objectives, and in other design phases (Frawley and Dyson, 2014; Tomitsch et al., 2021).

Representational approaches can be complemented by embodiment exercises to better imagine non-human struggles and goals (van Bommel and Boonman-Berson, 2022), and such embodiment exercises have already been used in approaches such as role playing games (Dernat et al., 2025; Ditzler et al., 2018; Harms et al., 2025). Embodiment exercises for including non-humans have been developed under various headers and in various forms, including the Council of Care (De La Rosa et al., 2025; Ressiore and de la Rosa, 2024), De-moo-cracy (van Veen and Helvoirt, 2024), or personas by human proxies (Frawley and Dyson, 2014). On discussing the Council of Care, de la Rosa describes how embodiment helps uncover power hierarchies amongst humans and non-humans as well as human – non-human relations (G. de la Rosa, personal communication, September 12, 2024). De la Rosa used a meditation exercise to have participants embody different non-humans before opening a council where humans would speak as if they were the non-human they were embodying. While this exercise does not include listening to non-human voices directly, it helps participants understand their own relationship to non-humans and their biases towards them. They had better results when doing the embodiment exercise outdoors in the ecosystem of the non-humans they were embodying, rather than in an indoor office setting or online (G. de la Rosa, personal communication, September 12, 2024).

It's important to note that the language of 'problem' and 'solution' has itself been critiqued as an anthropocentric, scientific way of framing. This linear approach, common in design processes, inherently centers human needs and objectives and often oversimplifies complex, interwoven challenges. In doing so, it risks reproducing the root causes of these challenges by failing to address them in meaningful ways (Bakırlıoğlu and Yetiş, 2024). These framings should be interrogated and destabilized to allow for more holistic articulations of intentions for change.

[2] Deliberation in this context refers to decision making processes amongst participants in participatory design. Deliberation is one model in political theory, but not the only approach to democratic decision making. For more-than-human decision making, other frameworks may also be useful, such as Chantal Mouffe's Agonistic Pluralism (Mouffe, 1999) which focuses on navigating trade-offs and conflicts, rather than focusing on consensus-building. Keeping to the scope of this work, we do not discuss the different democratic models of deliberation.

Table 1
Framework for reflection, presenting reflective questions for research and design and relevant concepts and methods to support reflection across design phases (phases based on a generalized approach that draws heavily on the RIO methodology (Bos et al., 2009)).

Phase	Agency	Temporality	Deliberation	Relevant concepts and methods
Problem definition and design objectives	Regarding the problem definition, why is this a problem and for whom? Whose agency is being fostered and whose is hindered in the framing of the problem definition and design objectives?	What time scales are problems and objectives defined on and how does that influence the outcome of the design process?	How do other beings perceive the problem and how do they act on it? Which human and non-human actors can shape the problem definition, and which cannot?	Citizen assembly (van Veen and Helvoirt, 2024), Personas (Frawley and Dyson, 2014; Tomitsch et al., 2021), Embodiment (van Bommel and Boonman-Berson, 2022)
System analysis	Which actors are considered, and how does this define what exists and therefore can act? How has non-human agency been considered in the systems analysis? How are the identified human and non-human actors a product of another set of actors? In other words, who influences the agency of system actors and how?	How are the time scales of the identified human and non-human actors considered? What temporality is the system boundary based on?	How are the identified human and non-human actors deliberating or negotiating with the system?	ANT (Yaneva, 2009), assemblage theory (Youn and Baek, 2024), affect (Darnhofer, 2020)
Design requirements or KPIs	How do requirement definitions define what non-human agency is and is not considered?	What timescales are implied or defined in the requirements and how does that influence the solution space? Do the timescales fit all relevant human and non-human actors?	How are non-humans invited to deliberate about their own requirements?	Personas (Frawley and Dyson, 2014; Tomitsch et al., 2021), Ethics of Care (EoC; Puig de la Bellacasa, 2015; Krzywoszynska, 2019), Citizen assembly (van Veen and Helvoirt, 2024), Need-based analysis (Jolibert et al., 2011)
Measurement practices	How does the measurement define the thing you are measuring, and what agency does it overlook?	Which non-humans are structurally measured, and which are excluded from measurements? How would adjusting measurement timescales influence such in- and exclusions? Who determines when baseline measurements are taken and in what ways are baseline measurements neutralizing past harms?	How does the measuring instrument influence the relationship between the measurer and the measured (e.g. does it dig holes, take plants or animals out of the system, establish a more affective relation between the observer and the observed)?	Multi-sensory communication (Poikolainen Rosén et al., 2022; van Bommel and Boonman-Berson, 2022), Mapping exercise (Meesters, 2023), Process-relational agronomy (Ditzler, 2022)
Selecting design solutions	How do proposed solutions change (better enable or hinder) the agency of system actors?	How can working with different timescales enable non-human deliberation in selecting or adjusting design solutions?	How can designers invite non-humans to influence and negotiate over the selection of design solutions?	Enabling space and voice (Donaldson, 2020), Animal deliberation (Driessen, 2014), Digital twins (Korenhof et al., 2021)
Overall	If this problem is solved, who wins and who loses? Is this desirable? Is there another problem definition that will have more desirable outcomes? What visualization tools are used in the design process and how does that influence our understanding of the non-humans in the system? Is that desirable? At every design stage: In what ways do our framings and assumptions influence, challenge, or maintain power dynamics within the system?			

5.2. System analysis

System analyses are used to map out the elements within a system and the inter-relation between system elements, and there are many approaches to map, diagnose and assess agricultural systems from different angles such as system components, material flows, system resilience, and innovation capacity (e.g. Conway, 1985; Hengsdijk et al., 1998; Kropff et al., 2001; Jones, 2014; Schut et al., 2015; Meuwissen et al., 2019). Performing a system analysis helps designers get an overview of how the system in question operates and where system improvements can be made. Generally, a technical approach is taken where, in the case of ASD, natural and mechanical processes are described. Taking a relational approach to systems analyses can uncover overlooked dynamics between non-humans by viewing these actors as intertwined rather than isolated. Key to adopting a relational approach is the recognition that farming systems are dynamic: not only do farmers' own goals and practices evolve, but also relations between non-human elements change frequently (e.g. pest and disease cycles), as well as markets, technologies, and more (Darnhofer, 2020; West et al., 2020). Delineations of what constitutes the system to be designed must therefore be conceptualized in a way that accounts for this dynamism; at a minimum, this could mean adopting an iterative approach to system definition. To include more relational ways of describing non-human system elements, actor-network theory (ANT) can be used to broaden how designers see agency amongst system elements and how system elements influence system dynamics (Yaneva, 2009). For example, ANT can help highlight how a farmer's decision to alter sowing schedules based on weather conditions, such as rain, is not solely a human-made decision but is shaped through interactions with the environment. Building on ANT, assemblage theory can be used to further help designers identify relevant, often overlooked, non-human stakeholders in the design process, thus facilitating their inclusion (Higgins et al., 2023; Youn and Baek, 2024). Assemblage theory brings an awareness of temporalities to ANT, by addressing the dynamic and ever-evolving nature of relationships amongst system actors.

The concept of affect, which highlights the capacity of entities to affect their surroundings, can further strengthen the process of recognizing the interconnectedness between system actors. Affect brings to light the inter-subjectivity between humans and non-humans, giving a fuller picture of how humans and non-humans influence each other in

what they can do and how they think (Darnhofer, 2020; van Bommel and Boonman-Berson, 2022; Carolan, 2017). In the context of systems analysis, this can broaden our view of relationships between system elements and how they influence, and deliberate with, each other.

Utilizing ANT, assemblages, and affect, system designers can better recognize the non-humans within a system and the influences they have, thus bringing to light important dynamics and challenging the idea that humans have full control over farming systems.

5.3. Design requirements and KPIs

Design requirements and Key Performance Indicators (or KPIs) describe the conditions for each stakeholder that a design concept must meet to be considered acceptable or successful. Agricultural system design processes often include requirements for non-humans, for example the nutrient requirements a certain crop needs to thrive or feed requirements for livestock (e.g. Moreira et al., 2023; Schreefel et al., 2022). Although sustainability and environmental impact assessment methods, such as multi-criteria analysis, consider effects on non-humans (Cicciù et al., 2022; Hebinck et al., 2021), these design requirements generally remain principally focused on the production of food for human consumption. However, the stage in which design requirements and KPIs are defined can be critical for including objectives other than those focused on production.

Relational approaches can be used to better understand how different system elements are intertwined and therefore how setting a requirement on one element will influence another element. Relational scholars argue that the 'objective', logical reasoning often strived for in science creates a detachment, resulting in moral distancing that allows for the exploitation of non-humans (Coeckelbergh, 2018). In the context of agricultural systems design, and specifically setting design requirements, one could argue that reducing this moral distance and acknowledging the illusion of objectivity may improve the consideration of non-humans in design requirements and outcomes, while highlighting the cultural, political, and economic choices that can underpin a design process (Legun, 2015a; Legun et al., 2022; Marder, 2012; Hebinck et al., 2021). Additionally, relational scholars highlight the agency of metrics themselves, noting how metrics co-produce realities in how they influence the actions of farmers and policymakers. Acknowledging the agency of metrics can afford designers the opportunity to define metrics as co-productive system elements (Rosin et al., 2017).

When using relational approaches, less emphasis is put on collecting objective and rational data, while emotional, physical, and affective experiences are included, for instance by considering a farmer's emotional connection to their land, animals, and machines (Darnhofer, 2020). Design requirements and KPIs are generally described with quantitative indicators and it is challenging to represent qualitative indicators in this format. For example, how does one measure farmer wellbeing, and can farmer wellbeing be related to, e.g., wellbeing of soil organisms? More research is needed on relational ways of measuring the success of design concepts (see Ditzler, 2022). This is further explored in 5.4 Measurement practices.

Ethics of Care (EoC) is a relational approach developed by feminist theorists which emphasizes meeting the needs of non-humans and aligning with the cycles or timelines of non-humans, with attentiveness and relationality. Attentiveness is needed to recognize the care needed by an entity. By working with the temporal rhythms of non-humans, rather than the typically used human-centered temporality, we can be more attentive to the needs of non-humans, allowing us to meet those needs for mutual care taking and improved sustainability (Puig de la Bellacasa, 2015; Krzywoszynska, 2019). This framework, focusing on care, being attentive, and working on different temporal rhythms, can help in defining requirements that revolve around the care needed for non-humans.

To enable more deliberation over decisions affecting non-humans, one could consider using a citizens' assembly in which non-humans are represented by human proxies who negotiate on the requirements necessary for their wellbeing (van Veen and Helvoirt, 2024). This method can also be used in later stages of a design process whenever design choices are being made. Methods that facilitate the representation of non-humans in deliberative processes can be helpful in better representing their needs and interests. For example, methods from HCI (human-computer interaction) and ACI (animal-computer interaction) can be used, such as personas that are developed to represent the needs and interests of non-humans in the process of setting design requirements (Frawley and Dyson, 2014; Tomitsch et al., 2021).[3] Personas can be useful in shedding light on our assumptions, beliefs, and experiences of non-humans in a design process.

A need-based analysis can be used to consider the needs of non-humans and make compromises when conflicts arise between different actors' needs (Jolibert et al., 2011). This method has been found to increase understanding of the different sides of a conflict when there are competing interests and including non-humans in this method can shift us away from prioritizing human interests in conflict resolution.

By further including non-humans in the requirement setting process, designers can ensure that the objectives of a design project are represented in the design requirements and there is less room for oversight on requirements that directly affect non-humans. This lays a good foundation for incorporating non-human interests in the rest of a design project.

5.4. Measurement practices

Measurements are a means of producing knowledge about a system. They might be used to better understand the state of affairs in a system to be designed, or to follow up on design outcomes and ensure KPIs are met. Measurement practices, including what researchers choose to measure, when, and how they measure it, shape what is uncovered and what remains hidden within a system. They are performative and have agency since they shape how designs are implemented and evolve (Meesters et al., 2023). While measurements aim to reveal the unseen, they also inherently create exclusions. For example, measures of agro-biodiversity may only account for certain target species that are considered relevant from a particular perspective, e.g. for biological pest control or for nature conservation. By excluding certain bodies/objects through the process of measuring, you exclude those bodies from participating (Gorissen et al., 2025; Meesters et al., 2023). These practices not only influence what is known and visible but also serve as tools of control and often enable extractivism (Turnhout et al., 2014).

To highlight the inclusions and exclusions inherent in measurement processes, one can map the effects of the various measurement methods employed, their temporal dimension (when and how long does measurements take place) and the material objects they create and exclude. This mapping can also be done to see what exclusions are made by the selection of indicators used for KPIs or design requirements (5.3 Design requirements). For instance, such a mapping exercise could describe which time scales are measured, which affects what knowledge is uncovered and how the measurement methods used are reinforcing power dynamics between different actors or enabling productivist agricultural models. Measurement campaigns in agricultural systems design experiments are often limited by the constraints of dominant funding schemes at the expense of long-term engagement and iterative approaches

[3] While personas are a useful tool, it is important to remember that an animal persona is a human-made tool that represents a current understanding of that animal, rather than being a true representation of the animal itself (Frawley and Dyson, 2014). Primary data should be emphasized in the development of personas that is collected through field research as there is a risk of overlooking critical issues not yet documented while using secondary data from literature (Tomitsch et al., 2021). This caution should be applied to all tools and methods used to represent or interpret non-human voices or intentions.

(Ditzler et al., 2021).

Further research could explore how measuring techniques, such as how soil health is measured, shape research outcomes. Ditzler (2022) highlights how commonly used soil fertility indicators, such as plant-available nitrogen and soil organic matter content, are often measured discretely at one or two points in time (e.g. the beginning and/or end of an experiment), whereas the processes occurring that affect these indicators are happening on multiple time scales. Additionally, Ditzler remarks that in agricultural systems design these indicators are used primarily to assess how successful a harvest will be and ignores how other beings are affected by soil health. In response, Ditzler proposes 'process-relational agronomy' in which measuring the success of a farm moves away from static indicators and towards holistic and relational accounts of success (Ditzler, 2022).

To overcome structural exclusions, and enhance more careful deliberation, it can be useful to employ a plurality of techniques that engage different senses (e.g. sight, sound, smell) to uncover otherwise hidden realities (Gorissen et al., 2025; Meesters, 2023; Poikolainen Rosén et al., 2022; van Bommel and Boonman-Berson, 2022). Improving measurement techniques might look like using different tools to 'hear' non-humans. For example, van Bommel and Boonman-Berson (2022) describe how multi-sensory communication can be helpful in interpreting non-human ways of communication to include non-human voices in nature conservation research. Poikolainen Rosén et al. (2022) describe techniques for 'noticing' non-humans, meaning bringing to light the overlooked, with a variety of measurement techniques employing various senses. Gorissen et al. (2025) describe how using a plurality of measuring techniques that value both oversight ("enabling farmers to optimize the efficiency of production") and insight ("offering a holistic and long-term understanding of ecological relations and how they affect production") can foster more diverse understandings of farm performance.

5.5. *Selecting design solutions*

Finally, we look to the phase of selecting design solutions. Design choices can be made with non-humans if we find ways to involve non-humans in decision making processes by making space for them to express their agency. Involving non-humans in the selection of design solutions takes rethinking the temporal dimension of design, contemplating and adjusting the time scales we are working in to allow them to express their agency and allow time for iteration and deliberation. Deliberating with non-humans might look like being perceptive to how they interact with a design concept and adjusting it as needed. For example, farmers adjusted the settings of milking robots based on how cows preferred to use the system (Driessen, 2014). In another example, farmers used digital fencing to control the grazing territory of their goats, resulting in a type of negotiation over what goat farming can look like (Søraa and Vik, 2021). While such interventions may enhance practical negotiations between humans and non-humans in the given circumstances, it is important to note that they are unable to challenge structural conditions and power dynamics regarding the larger agricultural system. To take it a step further, designers can draw on Donaldson's (2020) concept of enabling space and voice to actively foster the conditions to empower non-humans to express their agency to shape their environments.

Others look to novel technologies in digital agriculture, such as sensors, digital twins and artificial intelligence, to represent non-human entities, such as ecosystems or animals, or anticipate how system inputs will affect system outcomes (Pylianidis et al., 2021; Verdouw et al., 2021). Beyond representing non-humans, these technologies could also be used to give voice to non-humans in novel forms of participatory on-farm experimentation (Lacoste et al., 2022, 2025). Artificial intelligence could be used to interpret plant and animal 'communication', and a digital twin could be used to test out design solutions to anticipate the effects on non-humans, facilitating design choices in line with non-human objectives (Bakker, 2022). This could be a key area in which agri-food tech start-ups (Klerkx and Villalobos, 2024) could contribute to more inclusive future ASD. Generally sensors and digital twins are used to control non-humans for improved efficiency and can lead to further objectification of non-humans (Bos et al., 2018), but they can be used for the inclusion of non-human interests in design if used carefully (Korenhof et al., 2021). It's important to consider the interaction between human-made technologies and natural non-human temporalities, and how technologies alter our perception of time and the speed of decision-making processes.

6. Discussion and conclusion

Tackling contemporary climate and ecological crises requires fundamental, systemic changes in food systems. Agricultural systems design co-shapes broader food systems and thus has a key role to play in food systems transformations. We argue that expanding which actors are considered as participants in design processes beyond humans is an important pathway to drive transformative change. In this article, we have developed ways to engage non-humans as active participants in participatory design processes to systematically address broad sustainability goals for more democratic and transformative outcomes. Rather than assessing which conceptualization of more-than-human participation is true or has received the most evidence, this article explored the consequences of approaching ASD through different sets of assumptions for the possibilities of non-human participation. While the insights addressed in this article can be applied to many different cases and bears relevance for transition design in other systems (e.g. mobility and urban systems) (Ceschin and Gaziulusoy, 2016; Irwin, 2015; Pineda et al., 2024; Tsatsou et al., 2023), we focused on participatory agricultural systems design. Agriculture is an interesting case as inherently agricultural systems are human-made systems with the goal to extract a product from the system, namely food, fibre, and other biobased materials[4]. However, we try to advocate for an 'ethics of exclusion' (Giraud, 2019), in which designers are conscious about the inclusions and exclusions made.

Such engagements fundamentally transform agricultural systems design by: (1) revealing hidden trade-offs between human productivity goals and non-humans' needs and ecological resilience; (2) expanding methodological capacity to detect and interpret signals from soil systems, plant communities, and animal populations; and (3) elevating non-human interests from externalities to essential design parameters. This approach creates pathways towards sustainable food systems as well as broader bioeconomies by systematically opening up problem and solution spaces to consider the stakes, needs, and interests of non-humans to meet a broader set of sustainability goals. Including non-human needs in agricultural systems have been shown to trigger cascading positive effects in holistic and integrated ways (Rehman et al., 2022). We conclude this article with three critical reflections on the potential for including non-humans in ASD.

First, possibilities for participation in agricultural systems are not distributed equally, and such inequality is tied intimately to knowledge hierarchies (Turnhout, 2024). Whether actors are cast as active or passive, atemporal or with their own rhythms, and communicative or mute affects how power and responsibilities are distributed across agricultural systems. The theoretical approaches that we have consulted operationalize non-humans in various ways, which can point ASD scholars in various directions. ANT and assemblage theory render non-humans as influential in steering agricultural systems through material negotiation, simply because they possess particular properties or bodily abilities.

[4] In this sense, beyond having importance for food systems transformation, agricultural systems design also has importance for transformations of other systems such as energy and housing, for example through concepts such as bioeconomy.

This acknowledges non-humans as being relevant in ASD and encourages human agricultural actors to allow non-human courses to take their turn and to let go of an ideal of full controllability. Posthumanist and animal studies conceptualizations of non-human needs and interests more explicitly call for different sets of responsibilities for humans, based on values of justice and mutual care. These approaches direct designers towards processes that can foster a better distribution of agentic possibilities by attuning to non-human temporalities and modes of deliberation. Postcolonial and indigenous work powerfully addresses both why and how non-humans are key to consult in ASD, because they render non-humans as communicative and knowledgeable entities that embody lessons about living well together. This implies that it matters for ASD, and hence for agricultural realities, which theoretical frameworks, concepts and methods are invited in ASD processes.

Second, considering these interdisciplinary insights has not only implications for design outcomes, but also for design processes. Current agricultural systems design processes are human-centered by design, and selectively including some non-humans in these processes will not enable the fundamental changes to agricultural systems necessary to be transformative. This means that design processes in themselves require radical adjustment to account for non-human agency, temporality and deliberation. The linearity of many design processes contradicts the adaptivity needed to engage non-humans and work in more-than-human time scales. Therefore, it is urgently needed to assess the extent to which our current design processes are fit for meaningful inclusion of non-humans. This review demonstrated that a rapidly growing body of work from various plumage can lead ASD in improving design methods. Mapping exercises to highlight inclusions and exclusions made in the design process, embodiment exercises to facilitate participants taking on different roles, citizen assemblies to negotiate between actors on design choices, and enabling space for non-humans to make choices on how they interact with a design are just some of the practical ways designers can participate with non-humans in design. However, to do so, design processes need to be designed for including non-human voices, for instance by creating more inclusive design protocols.

Third, our work articulates that there are various degrees of intervening in power relations, and how this in turn affects the transformative potential of ASD thinking. This not only entails challenging incumbent power relations between different human actors and organizations in agri-food systems (cf. Clapp, 2021; Rossi et al., 2019), but also entails challenging the power relations that reproduce the separation between humans and non-humans in agri-food systems (cf. Tschersich and Kok, 2022). For ASD to be inclusive of non-humans, this ultimately requires humans to disrupt the dominance of human values, temporalities, needs, and interests, so non-humans can take more space and enter in negotiation on terms set outside of current agricultural production systems (Bastian, 2017; Meesters, 2023). Disrupting dominant systems leads to shifts in power balances, and it is important to consistently and continuously scrutinize who loses and gains influence, and whether that is desirable and for whom. Participatory processes have been demonstrated to reinforce and even strengthen hierarchies when they do not allow for adjusting the rules of the game (Bastian, 2017; Cooke and Kothari, 2001; Turnhout et al., 2020). Determining who wins and who loses is complex, as human and non-human interests are often intertwined, and the objectives of sustainability, biodiversity, and improved animal welfare frequently serve human interests, such as enhancing production and human livelihoods. While representing human and non-human interests simultaneously does not have to be mutually exclusive, genuine consideration of the interests of non-humans is uncommon, requiring a shift in how non-humans are considered. This is challenging, as fundamental changes in values and power dynamics often run into resistance of status quo actors and organizations. While working with vested interests (such as large businesses and governments) can be considered an important avenue to realize change, scholars have warned to be wary of collaborating with actors that benefit from the exploitation of the natural world, which often results in the watering-down of the, often ambitious, objectives set out at the start of projects (Turnhout et al., 2020). For instance, studies point out that radical agricultural frameworks, such as agroecology and regenerative agriculture, have been coopted by the mainstream and watered down, due to a lack of consideration of power and equity issues (Bless et al., 2023; Tittonell et al., 2022; Walthall et al., 2024), highlighting the importance of addressing power and equity for transformational agricultural systems.

In view of these reflections, to advance research on non-human participation in ASD, further research could focus on questions such as:

- What is the interaction between human and non-human participation in participatory processes?
- Which methods for involving non-humans in participatory processes are effective, for who, and how, in practice?
- What is the influence of different methods on the transformative potential of design outcomes?
- How can research and innovation projects support designers to do this type of work and create an evolution of what transdisciplinary science and innovation entails?
- What role can new technologies have in creating systems that facilitate deliberation between humans and non-humans, and what are the risks?

Finally, in this article we have focused on practical applications, though these applications in practice will not be without hurdles, given current research schemes (e.g. time and budget limitations), knowledge gaps (e.g. how to enable non-humans to speak for themselves), and power distributions (e.g. how to balance human and non-human needs when they are mutually exclusive). This shows that agricultural systems design cannot be designed differently in isolation from larger academic and societal challenges. Hence, it highlights that, in addition to novel research methods, there is a need for incumbent agri-food research and innovation systems to tackle these hurdles and provide support for projects and initiatives that seek to promote non-human participation in ASD. Nevertheless, we believe this article shows that engaging with terms, words, and ways of thinking from unexpected places can provide practical interventions to take a step in the right direction.

CRediT authorship contribution statement

Tatiana Moreira: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Marieke E. Meesters:** Writing – review & editing, Writing – original draft, Conceptualization. **Kristiaan P.W. Kok:** Writing – review & editing, Visualization, Conceptualization, Writing – original draft. **Katharine Legun:** Writing – review & editing, Funding acquisition, Conceptualization. **Lenora Ditzler:** Writing – review & editing, Conceptualization. **Laurens Klerkx:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization, Writing – original draft.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used generative AI for assistance in shortening and improving readability of text. All original text was written by the authors. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors have no interests to declare.

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Appendix A. Supplementary data

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Data availability

No data was used for the research described in the article.

References

Bakırlıoğlu, Y., Yetiş, E.Ö., 2024. Daunted by design: creating tools of slow violence. Innov. Europ. J. Soc. Sci. Res. 1–15. https://doi.org/10.1080/13511610.2024.2395268.

Bakker, K., 2022. The Sounds of Life: How Digital Technology Is Bringing us Closer to the Worlds of Animals and Plants. Princeton University Press, New Jersey.

Barnaud, C., van Paassen, A., Trébuil, G., Promburom, T., Bousquet, F., 2010. Dealing with power games in a companion modelling process: lessons from community water management in Thailand highlands. J. Agric. Educ. Ext. 16, 55–74. https://doi.org/10.1080/13892240903533152.

Barry, A., 2013. Material Politics: Disputes along the Pipeline. John Wiley & Sons.

Bastian, M., 2017. Towards a more-than-human participatory research. In: Franklin, In A. (Ed.), The Routledge International Handbook of More-Than-Human Studies, 1st ed. Routledge, pp. 404–419. https://doi.org/10.4324/9781003262619-29.

Berthet, E.T., Barnaud, C., Girard, N., Labatut, J., Martin, G., 2016. How to foster agroecological innovations? A comparison of participatory design methods. J. Environ. Plan. Manag. 59 (2), 280–301. https://doi.org/10.1080/09640568.2015.1009627.

Berthet, E.T., Hickey, G.M., Klerkx, L., 2018. Opening design and innovation processes in agriculture: insights from design and management sciences and future directions. Agric. Syst. 165, 111–115. https://doi.org/10.1016/j.agsy.2018.06.004.

Bessai, R., Bendor, R., Balkenende, R., 2024. Designing with more-than-human temporalities. In: DRS Biennial Conference Series. DRS2024: Boston, Boston, USA. https://doi.org/10.21606/drs.2024.438.

Bless, A., Davila, F., Plant, R., 2023. A genealogy of sustainable agriculture narratives: implications for the transformative potential of regenerative agriculture. Agric. Hum. Values 40 (4), 1379–1397. https://doi.org/10.1007/s10460-023-10444-4.

Blok, V., Gremmen, B., 2018. Agricultural technologies as living machines: toward a biomimetic conceptualization of smart farming technologies. Ethics Policy Environ. 21, 246–263. https://doi.org/10.1080/21550085.2018.1509491.

Bos, A.P., Grin, J., 2008. "Doing" reflexive modernization in pig husbandry: the hard work of changing the course of a river. Sci. Technol. Hum. Values 33 (4), Article 4. https://doi.org/10.1177/0162243907306697.

Bos, A.P., Groot Koerkamp, P.W.G., Gosselink, J.M.J., Bokma, S., 2009. Reflexive interactive design and its application in a project on sustainable dairy husbandry systems. Outlook Agric. 38 (2009), 2. https://doi.org/10.5367/000000009788632386.

Bos, J.M., Bovenkerk, B., Feindt, P.H., van Dam, Y.K., 2018. The quantified animal: precision livestock farming and the ethical implications of objectification. Food Ethics 2, 77–92. https://doi.org/10.1007/s41055-018-00029-x.

Brun, J., Jeuffroy, M.-H., Pénicaud, C., Cerf, M., Meynard, J.-M., 2021. Designing a research agenda for coupled innovation towards sustainable agrifood systems. Agric. Syst. 191, 103143. https://doi.org/10.1016/j.agsy.2021.103143.

Çakmakçı, R., Salık, M.A., Çakmakçı, S., 2023. Assessment and principles of environmentally sustainable food and agriculture systems. Agriculture 13 (5), 1073. https://doi.org/10.3390/agriculture13051073.

Campbell, H., 2020. Farming inside Invisible Worlds: Modernist Agriculture and its Consequences. Bloomsbury Academic, p. 224. https://doi.org/10.5040/9781350120570.

Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecol. Soc. 22 (4). https://doi.org/10.5751/ES-09595-220408.

Carberry, P.S., Hochman, Z., McCown, R.L., Dalgliesh, N.P., Foale, M.A., Poulton, P.L., Hargreaves, J.N.G., Hargreaves, D.M.G., Cawthray, S., Hillcoat, N., Robertson, M.J., 2002. The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. Agric. Syst. 74, 141–177. https://doi.org/10.1016/S0308-521X(02)00025-2.

Carolan, M., 2017. Agro-digital governance and life itself: food politics at the intersection of code and affect. Sociol. Rural. 57, 816–835. https://doi.org/10.1111/soru.12153.

Caron, P., Ferreroy de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., Verburg, G., 2018. Food systems for sustainable development: proposals for a profound four-part transformation. Agron. Sustain. Dev. 38, 1–12. https://doi.org/10.1007/s13593-018-0519-1.

Cerf, M., Jeuffroy, M.-H., Prost, L., Meynard, J.-M., 2012. Participatory design of agricultural decision support tools: taking account of the use situations. Agron. Sustain. Dev. 32 (4), 899–910. https://doi.org/10.1007/s13593-012-0091-z.

Ceschin, F., Gaziulusoy, I., 2016. Evolution of design for sustainability: From product design to design for system innovations and transitions. Design Studies 47, 118–163.

Cicciù, B., Schramm, F., Schramm, V.B., 2022. Multi-criteria decision making/aid methods for assessing agricultural sustainability: a literature review. Environ. Sci. Pol. 138, 85–96. https://doi.org/10.1016/j.envsci.2022.09.020.

Clapp, J., 2021. The problem with growing corporate concentration and power in the global food system. Nat. Food 2 (6), 404–408. https://doi.org/10.1038/s43016-021-00297-7.

Coeckelbergh, M., 2018. What do we mean by a relational ethics? Growing a relational approach to the moral standing of plants, robots, and other non-humans. In: Plant Ethics. Routledge.

Contesse, M., Duncan, J., Legun, K., Klerkx, L., 2021. Unravelling non-human agency in sustainability transitions. Technol. Forecast. Soc. Chang. 166, 120634. https://doi.org/10.1016/j.techfore.2021.120634.

Conway, G.R., 1985. Agroecosystem analysis. Agric. Adm. 20, 31–55. https://doi.org/10.1016/0309-586X(85)90064-0.

Cooke, B., Kothari, U., 2001. Participation: The New Tyranny? Zed Books.

Darnhofer, I., 2020. Farming from a process-relational perspective: making openings for change visible. Sociol. Rural. 60 (2), 505–528. https://doi.org/10.1111/soru.12294.

de Bruin, A., de Boer, I.J.M., Faber, N.R., de Jong, G., Termeer, K.J.A.M., de Olde, E.M., 2024. Easier said than defined? Conceptualising justice in food system transitions. Agric. Hum. Values 41 (1), 345–362. https://doi.org/10.1007/s10460-023-10482-y.

De La Rosa, G., Ludwig, D., Nieves, A., El-Hani, C.N., 2025. Between confluence and disenfranchisement: the role of power dynamics in transdisciplinary research. Curr. Res. Environ. Sustain. 10, 100300. https://doi.org/10.1016/j.crsust.2025.100300.

Dernat, S., Grillot, M., Andreotti, F., Martel, G., 2025. A sustainable game changer? Systematic review of serious games used for agriculture and research agenda. Agric. Syst. 222, 104178. https://doi.org/10.1016/j.agsy.2024.104178.

Ditzler, L., 2022. Towards Diversified Industrial Cropping Systems? Doctoral Thesis Wageningen University. https://library.wur.nl/WebQuery/wurpubs/603203.

Ditzler, L., Driessen, C., 2022. Automating agroecology: how to design a farming robot without a Monocultural mindset? J. Agric. Environ. Ethics 35 (1), 2. https://doi.org/10.1007/s10806-021-09876-x.

Ditzler, L., Klerkx, L., Chan-Dentoni, J., Posthumus, H., Krupnik, T.J., Ridaura, S.L., Andersson, J.A., Baudron, F., Groot, J.C.J., 2018. Affordances of agricultural systems analysis tools: a review and framework to enhance tool design and implementation. Agric. Syst. 164, 20–30. https://doi.org/10.1016/j.agsy.2018.03.006.

Ditzler, L., van Apeldoorn, D.F., Pellegrini, F., Antichi, D., Bàrberi, P., Rossing, W.A.H., 2021. Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. Agron. Sustain. Dev. 41 (2), 26. https://doi.org/10.1007/s13593-021-00678-z.

Dogliotti, S., Rossing, W.A.H., van Ittersum, M.K., 2004. Systematic design and evaluation of crop rotations enhancing soil conservation, soil fertility and farm income: a case study for vegetable farms in South Uruguay. Agric. Syst. 80 (3), 277–302. https://doi.org/10.1016/j.agsy.2003.08.001.

Donaldson, S., 2020. Animal agora: animal citizens and the democratic challenge. Soc. Theory Pract. 46 (4), 709–735. https://doi.org/10.5840/soctheorpract202061296.

Driessen, C., 2014. Animal Deliberation. In: Wissenburg, M., Schlosberg, D. (Eds.), Political Animals and Animal Politics. Palgrave Macmillan UK, pp. 90–104. https://doi.org/10.1007/978-1-349-68308-6_7.

Elzen, B., Bos, B., 2019. The RIO approach: design and anchoring of sustainable animal husbandry systems. Technol. Forecast. Soc. Chang. 145, 141–152. https://doi.org/10.1016/j.techfore.2016.05.023.

Ermine, W., 2007. The ethical space of engagement. Ind. Law J. 6 (1), 193.

FAO, F, 2018. The future of food and agriculture: alternative pathways to 2050. In: Food and Agriculture Organization of the United Nations Rome, 60.

Ferguson, R.S., Lovell, S.T., 2014. Permaculture for agroecology: design, movement, practice, and worldview. A review. Agron. Sustain. Dev. 34 (2), 251–274. https://doi.org/10.1007/s13593-013-0181-6.

Fleck, J., 1993. Innofusion: Feedback in the innovation process. In: Stowell, F.A., West, D., Howell, J.G. (Eds.), Systems Science: Addressing Global Issues. Springer, US, Boston, MA, pp. 169–174.

Forlano, L., 2017. Posthumanism and Design. She Ji. The Journal of Design, Economics, and Innovation 3, 16–29.

Frawley, J.K., Dyson, L.E., 2014. Animal personas: acknowledging non-human stakeholders in designing for sustainable food systems. In: Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: The Future of Design. https://doi.org/10.1145/2686612.2686617.

Geiselmann, R., Tsourgianni, A., Deroy, O., Harris, L.T., 2023. Interacting with agents without a mind: the case for artificial agents. Curr. Opin. Behav. Sci. 51. https://doi.org/10.1016/j.cobeha.2023.101282.
Gerber, S., Hiernaux, Q., 2022. Plants as machines: history, philosophy and practical consequences of an idea. J. Agric. Environ. Ethics 35 (1), 4. https://doi.org/10.1007/s10806-021-09877-w.
Giraud, E.H., 2019. What Comes after Entanglement?: Activism, Anthropocentrism, and an Ethics of Exclusion. Duke University Press.
Glover, D., 2022. Affordances and agricultural technology. J. Rural. Stud. 94, 73–82. https://doi.org/10.1016/j.jrurstud.2022.05.007.
Gorissen, L., Konrad, K., Turnhout, E., 2025. Sensors and sensing practices: shaping farming system strategies toward agricultural sustainability. Agric. Hum. Values 1–19. https://doi.org/10.1007/s10460-024-10686-w.
Grahmann, K., Reckling, M., Hernández-Ochoa, I., Donat, M., Bellingrath-Kimura, S., Ewert, F., 2024. Co-designing a landscape experiment to investigate diversified cropping systems. Agric. Syst. 217, 103950. https://doi.org/10.1016/j.agsy.2024.103950.
Gualtieri, G., Druta, O., Velzing, E., 2023. Preliminary study of participatory and nature-inclusive design approaches. In: De Sainz Molestina, D., Galluzzo, L., Rizzo, F., Spallazzo, D. (Eds.), IASDR 2023: Life-Changing Design, 9–13 October, Milan, Italy. https://doi.org/10.21606/iasdr.2023.718.
Harms, P., Joshi, N., Knauß, S., 2025. Designing multispecies role-playing games: from human-nature partnerships towards multispecies justice. NPJ Urban Sustain. 5, 68.
Hebinck, A., Zurek, M., Achterbosch, T., Forkman, B., Kuijsten, A., Kuiper, M., Nørrung, B., Veer, P.V.T., Leip, A., 2021. A sustainability compass for policy navigation to sustainable food systems. Glob. Food Sec. 29, 100546. https://doi.org/10.1016/j.gfs.2021.100546.
Hengsdijk, H., van Ittersum, M.K., Rossing, W.A.H., 1998. Quantitative analysis of farming systems for policy formulation: development of new tools. Agric. Syst. 58, 381–394. https://doi.org/10.1016/S0308-521X(98)00037-7.
Higgins, V., Bryant, M., Howell, A., Battersby, J., 2017. Ordering adoption: materiality, knowledge and farmer engagement with precision agriculture technologies. J. Rural. Stud. 55, 193–202. https://doi.org/10.1016/j.jrurstud.2017.08.011.
Higgins, V., van der Velden, D., Bechtet, N., Bryant, M., Battersby, J., Belle, M., Klerkx, L., 2023. Deliberative assembling: Tinkering and farmer agency in precision agriculture implementation. Journal of Rural Studies 100, 103023.
Holy-Luczaj, M., Blok, V., 2021. Hybrids and the boundaries of moral Considerability or revisiting the idea of non-instrumental value. Philos. Technol. 34, 223–242. https://doi.org/10.1007/s13347-019-00380-9.
Hoppe, K., 2019. Responding as composing: towards a post-anthropocentric, feminist ethics for the Anthropocene. Distinktion J. Soc. Theory 21 (2), 125–142. https://doi.org/10.1080/1600910X.2019.1618360.
Huttunen, S., Turunen, A., Kaljonen, M., 2022. Participation for just governance of food-system transition. Sustain Sci Pract Policy 18 (1), 500–514. https://doi.org/10.1080/15487733.2022.2088187.
Irwin, T., 2015. Transition Design: A Proposal for a New Area of Design Practice, Study, and Research. Design and Culture 7 (2), 229–246. https://doi.org/10.1080/17547075.2015.1051829.
Jansen, K., Vellema, S., 2011. What is technography? NJAS Wageningen J. Life Sci. 57 (3–4), 169–177. https://doi.org/10.1016/j.njas.2010.11.003.
Jolibert, C., Max-Neef, M., Rauschmayer, F., Paavola, J., 2011. Should we care about the needs of non-humans? Needs assessment: a tool for environmental conflict resolution and sustainable organization of living beings. Environ. Policy Gov. 21 (4), 259–269. https://doi.org/10.1002/eet.578.
Jones, P.H., 2014. Systemic design principles for complex social systems. In: Metcalf, G.S. (Ed.), Social Systems and Design Springer Japan, Tokyo, pp. 91–128.
Juventia, S.D., Selin Norén, I.L.M., van Apeldoorn, D.F., Ditzler, L., Rossing, W.A.H., 2022. Spatio-temporal design of strip cropping systems. Agric. Syst. 201, 103455. https://doi.org/10.1016/j.agsy.2022.103455.
Kanter, D.R., Schwoob, M.H., Baethgen, W.E., Bervejillo, J.E., Carriquiry, M., Dobermann, A., de Lima, J.M.S., 2016. Translating the sustainable development goals into action: a participatory backcasting approach for developing national agricultural transformation pathways. Glob. Food Sec. 10, 71–79. https://doi.org/10.1016/j.gfs.2016.08.002.
Kimmerer, R.W., 2013. Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants, 1st ed. (Milkweed Editions).
Klerkx, L., Villalobos, P., 2024. Are AgriFoodTech start-ups the new drivers of food systems transformation? An overview of the state of the art and a research agenda. Glob. Food Sec. 40, 100726. https://doi.org/10.1016/j.gfs.2023.100726.
Kok, K.P.W., Klerkx, L., 2023. Addressing the politics of mission-oriented agricultural innovation systems. Agric. Syst. 211, 103747. https://doi.org/10.1016/j.agsy.2023.103747.
Korenhof, P., Blok, V., Kloppenburg, S., 2021. Steering representations—towards a critical understanding of digital twins. Philos. Technol. 34 (4), 1751–1773. https://doi.org/10.1007/s13347-021-00484-1.
Kothari, A., Demaria, F., Acosta, A., 2014. Buen Vivir, degrowth and ecological Swaraj: alternatives to sustainable development and the green economy. Development 57 (3), 362–375. https://doi.org/10.1057/dev.2015.24.
Kropff, M.J., Bouma, J., Jones, J.W., 2001. Systems approaches for the design of sustainable agro-ecosystems. Agric. Syst. 70, 369–393. https://doi.org/10.1016/S0308-521X(01)00052-X.
Krzywoszynska, A., 2019. Caring for soil life in the Anthropocene: the role of attentiveness in more-than-human ethics. Trans. Inst. Br. Geogr. 44 (4), 661–675. https://doi.org/10.1111/tran.12293.
Lacoste, M., Bellon-Maurel, V., Piot-Lepetit, I., Cook, S., Tremblay, N., Longchamps, L., McNee, M., Taylor, J., Ingram, J., Adolwa, I., Hall, A., 2025. Farmer-centric On-Farm Experimentation: digital tools for a scalable transformative pathway. Agronomy for Sustainable Development 45, 18.
Lacoste, M., Cook, S., McNee, M., Gale, D., Ingram, J., Bellon-Maurel, V., MacMillan, T., Sylvester-Bradley, R., Kindred, D., Bramley, R., Tremblay, N., Longchamps, L., Thompson, L., Ruiz, J., García, F.O., Maxwell, B., Griffin, T., Oberthür, T., Huyghe, C., Zhang, W., McNamara, J., Hall, A., 2022. On-Farm Experimentation to transform global agriculture. Nature Food 3, 11–18.
Latour, B., 1992. Where are the missing masses? The sociology of a few mundane artifacts. In: Bijker, W.E., Law, J. (Eds.), Shaping Technology/Building Society: Studies in Sociotechnical Change. MIT Press, Cambridge, MA, pp. 225–258.
Latour, B., 2007. Reassembling the Social: An Introduction to Actor-Network-Theory. OUP Oxford.
Le Gal, P.-Y., Dugué, P., Faure, G., Novak, S., 2011. How does research address the design of innovative agricultural production systems at the farm level? A review. Agric. Syst. 104 (9), 714–728. https://doi.org/10.1016/j.agsy.2011.07.007.
Leeuwis, C., 1999. Integral technology design as a process of learning and negotiation. A social science perspective on interactive prototyping. In: Leeuwis, C. (Ed.), Integral Design: Innovation in Agriculture and Natural Resource Management. Wageningen, Mansholt Institute, pp. 123–144.
Leeuwis, C., 2000. Reconceptualizing participation for sustainable rural development: towards a negotiation approach. Dev. Chang. 31, 931–959. https://doi.org/10.1111/1467-7660.00184.
Legun, K., 2015a. Club apples: a biology of markets built on the social life of variety. Econ. Soc. 44 (2), 293–315. https://doi.org/10.1080/03085147.2015.1013743.
Legun, K., 2015b. Tiny trees for trendy produce: dwarfing technologies as assemblage actors in orchard economies. Geoforum 65, 314–322. https://doi.org/10.1016/j.geoforum.2015.03.009.
Legun, K., Burch, K.A., Klerkx, L., 2023. Can a robot be an expert? The social meaning of skill and its expression through the prospect of autonomous AgTech. Agriculture and Human Values 40, 501–517.
Legun, K., Comi, M., Vicol, M., 2022. New aesthetic regimes: the shifting global political ecology of aroma hops. Geoforum 128, 148–157. https://doi.org/10.1016/j.geoforum.2021.12.004.
Marder, M., 2012. Resist like a plant! On the vegetal life of political movements. Peace Stud. J. 5 (1), 24–32.
Marres, N., Lezaun, J., 2011. Materials and devices of the public: an introduction. Econ. Soc. 40 (4), 489–509. https://doi.org/10.1080/03085147.2011.602293.
Martin, G., Felten, B., Duru, M., 2011. Forage rummy: a game to support the participatory design of adapted livestock systems. Environ. Model. Softw. 26, 1442–1453. https://doi.org/10.1016/j.envsoft.2011.08.013.
Martin, G., Martin-Clouaire, R., Duru, M., 2013. Farming system design to feed the changing world. A review. Agron. Sustain. Dev. 33 (1), 131–149. https://doi.org/10.1007/s13593-011-0075-4.
Massarella, K., Nygren, A., Fletcher, R., Büscher, B., Kiwango, W.A., Komi, S., Percequillo, A.R., 2021. Transformation beyond conservation: how critical social science can contribute to a radical new agenda in biodiversity conservation. Curr. Opin. Environ. Sustain. 49, 79–87. https://doi.org/10.1016/j.cosust.2021.03.005.
Meesters, M.E., 2023. Posthumanist Participation: Beyond Extractivism in the Dutch Wadden Sea Area. Doctoral Thesis. Wageningen University. https://doi.org/10.18174/633108.
Meesters, M.E., Turnhout, E., Behagel, J.H., 2023. Negotiating salt worlds: causation and material participation. Critic. Policy Stud. 17 (2), 297–315. https://doi.org/10.1080/19460171.2022.2078731.
Meijer, E., 2019. When Animals Speak: Toward an Interspecies Democracy, vol. 1. NYU Press.
Merchant, C., 2006. The scientific revolution and the death of nature. Isis 97 (3), 513–533. https://doi.org/10.1086/508090.
Meuwissen, M.P.M., Feindt, P.H., Spiegel, A., Termeer, C.J.A.M., Mathijs, E., Mey, Y.D., Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., Ciechomska, A., Accatino, F., Kopainsky, B., Poortvliet, P.M., Candel, J. J.L., Maye, D., Severini, S., Senni, S., Soriano, B., Lagerkvist, C.-J., Peneva, M., Gavrilescu, C., Reidsma, P., 2019. A framework to assess the resilience of farming systems. Agric. Syst. 176, 102656. https://doi.org/10.1016/j.agsy.2019.102656.
Meynard, J.-M., Jeuffroy, M.-H., Le Bail, M., Lefèvre, A., Magrini, M.-B., Michon, C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems. Agric. Syst. 157, 330–339. https://doi.org/10.1016/j.agsy.2016.08.002.
Moreira, T., Groot Koerkamp, P., Janssen, A., Stomph, T.-J., van der Werf, W., 2023. Breaking the mould: developing innovative crop protection strategies with reflexive interactive design. Agric. Syst. 210, 103727. https://doi.org/10.1016/j.agsy.2023.103727.
Mouffe, C., 1999. Deliberative democracy or agonistic pluralism? Soc. Res. 66 (3), 745–758.
Murgue, C., Therond, O., Leenhardt, D., 2015. Toward integrated water and agricultural land management: participatory design of agricultural landscapes. Land Use Policy 45, 52–63. https://doi.org/10.1016/j.landusepol.2015.01.011.
Nicenboim, I., Lindley, J., Zaga, C., Berger, A., Forlano, L., 2024. More-Than-Human Design in Practice. DRS2024: Boston, Boston, USA. https://doi.org/10.21606/drs.2024.114.
Paré, G., Kitsiou, S., 2017. Chapter 9 methods for literature reviews. In: Handbook of eHealth Evaluation: An Evidence-Based Approach. University of Victoria.
Pelzer, E., Bonifazi, M., Soulié, M., Guichard, L., Quinio, M., Ballot, R., Jeuffroy, M.-H., 2020. Participatory design of agronomic scenarios for the reintroduction of legumes into a French territory. Agric. Syst. 184, 102893. https://doi.org/10.1016/j.agsy.2020.102893.

Pigford, A.A.E., Hickey, G.M., Klerkx, L., 2018. Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in sustainability transitions. Agric. Syst. 164, 116–121. https://doi.org/10.1016/j.agsy.2018.04.007.
Pineda, A.F.V., Elle, M., Iuel-Jensen, J., 2024. The role of design in sustainable transitions: The case of mobility in Greater Copenhagen. Environmental Innovation and Societal Transitions 50, 100807.
Plummer, P., Andersson, J., Lennerfors, T.T., 2024. Foraging for development: an analysis of the Swedish wild berry innovation system. Agric. Syst. 216. https://doi.org/10.1016/j.agsy.2024.103901.
Poikolainen Rosén, A., Normark, M., Wiberg, M., 2022. Towards more-than-human-centred design: learning from gardening. Int. J. Des. 16 (3), 21–36. https://doi.org/10.57698/v16i3.02.
Prost, L., 2021. Revitalizing agricultural sciences with design sciences. Agric. Syst. 193, 103225. https://doi.org/10.1016/j.agsy.2021.103225.
Prost, L., Reau, R., Paravano, L., Cerf, M., Jeuffroy, M.H., 2018. Designing agricultural systems from invention to implementation: the contribution of agronomy. Lessons from a case study. Agric. Syst. 164, 122–132. https://doi.org/10.1016/j.agsy.2018.04.009.
Pschetz, L., Koppel, K., Bastian, M., 2024. Design for temporal cohabitation. In: Extended Abstracts of the CHI Conference on Human Factors in Computing Systems, pp. 1–8. https://doi.org/10.1145/3613905.3644068.
Puente-Rodríguez, D., Bos, A.P., Groot Koerkamp, P.W.G., 2019. Rethinking livestock production systems on the Galápagos Islands: organizing knowledge-practice interfaces through reflexive interactive design. Environ. Sci. Pol. 101, 166–174. https://doi.org/10.1016/j.envsci.2019.08.019.
Puig de la Bellacasa, M., 2015. Making time for soil: technoscientific futurity and the pace of care. Soc. Stud. Sci. 45 (5), 691–716. https://doi.org/10.1177/0306312715599851.
Pylianidis, C., Osinga, S., Athanasiadis, I.N., 2021. Introducing digital twins to agriculture. Comput. Electron. Agric. 184.
Quinio, M., Jeuffroy, M.H., Guichard, L., Salazar, P., Détienne, F., 2022. Analyzing co-design of agroecology-oriented cropping systems: lessons to build design-support tools. Agron. Sustain. Dev. 42 (4), 72. https://doi.org/10.1007/s13593-022-00772-w.
Reckling, M., Bergkvist, G., Watson, C.A., Stoddard, F.L., Bachinger, J., 2020. Re-designing organic grain legume cropping systems using systems agronomy. Eur. J. Agron. 112, 125951. https://doi.org/10.1016/j.eja.2019.125951.
Rehman, A., Farooq, M., Lee, D.J., Siddique, K.H., 2022. Sustainable agricultural practices for food security and ecosystem services. Environ. Sci. Pollut. Res. 29 (56), 84076–84095. https://doi.org/10.1007/s11356-022-23635-z.
Ressiore, A., de la Rosa, G., 2024. The Council of Care. Geos Project. https://www.geos-project.org/projects/the-council-of-care.
Robertson, T., Simonsen, J., 2012. Challenges and opportunities in contemporary participatory design. Des. Issues 28 (3), 3–9. https://doi.org/10.1162/DESI_a_00157.
Rockström, J., Edenhofer, O., Gaertner, J., DeClerck, F., 2020. Planet-proofing the global food system. Nat. Food 1 (1), 3–5. https://doi.org/10.1038/s43016-019-0010-4.
Romera, A.J., Bos, A.P., Neal, M., Eastwood, C.R., Chapman, D., McWilliam, W., Royds, D., O'Connor, C., Brookes, R., Connolly, J., Hall, P., Clinton, P.W., 2020. Designing future dairy systems for New Zealand using reflexive interactive design. Agric. Syst. 181, 102818. https://doi.org/10.1016/j.agsy.2020.102818.
Rose, D.C., Sutherland, W.J., Parker, C., Lobley, M., Winter, M., Morris, C., Twining, S., Ffoulkes, C., Amano, T., Dicks, L.V., 2016. Decision support tools for agriculture: towards effective design and delivery. Agric. Syst. 149, 165–174. https://doi.org/10.1016/j.agsy.2016.09.009.
Rosin, C.J., Legun, K.A., Campbell, H., Sautier, M., 2017. From compliance to co-production: emergent forms of agency in sustainable wine production in New Zealand. Environ. Plan. A Econ. Space 49 (12), 2780–2799. https://doi.org/10.1177/0308518X17733747.
Rossi, A., Bui, S., Marsden, T., 2019. Redefining power relations in agrifood systems. J. Rural. Stud. 68, 147–158. https://doi.org/10.1016/j.jrurstud.2019.01.002.
Roux-Rosier, A., Azambuja, R., Islam, G., 2018. Alternative visions: permaculture as imaginaries of the Anthropocene. Organization 25 (4), 550–572. https://doi.org/10.1177/1350508418778647.
Runhaar, H., 2017. Governing the transformation towards 'nature-inclusive' agriculture: insights from the Netherlands. Int. J. Agric. Sustain. 15 (4), 340–349. https://doi.org/10.1080/14735903.2017.1312096.
Ryan, M., 2023. The social and ethical impacts of artificial intelligence in agriculture: mapping the agricultural AI literature. AI & Soc. 38 (6), 2473–2485. https://doi.org/10.1007/s00146-021-01377-9.
Salembier, C., Segrestin, B., Berthet, E., Weil, B., Meynard, J.-M., 2018. Genealogy of design reasoning in agronomy: lessons for supporting the design of agricultural systems. Agric. Syst. 164, 277–290. https://doi.org/10.1016/j.agsy.2018.05.005.
Salembier, C., Segrestin, B., Sinoir, N., Templier, J., Weil, B., Meynard, J.-M., 2020. Design of equipment for agroecology: coupled innovation processes led by farmer-designers. Agric. Syst. 183, 102856. https://doi.org/10.1016/j.agsy.2020.102856.
Schreefel, L., van Zanten, H.H.E., Groot, J.C.J., Timler, C.J., Zwetsloot, M.J., Schrijver, A.P., Creamer, R.E., Schulte, R.P.O., de Boer, I.J.M., 2022. Tailor-made solutions for regenerative agriculture in the Netherlands. Agric. Syst. 203, 103518. https://doi.org/10.1016/j.agsy.2022.103518.
Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L.C., Raboanarielina, C.M., Adegbola, P.Y., van Ast, A., Bastiaans, L., 2015. RAAIS: rapid appraisal of agricultural innovation systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agric. Syst. 132, 1–11. https://doi.org/10.1016/j.agsy.2014.08.009.
Sella, I., Hadary, T., Rella, A.J., Riegl, B., Swack, D., Perkol-Finkel, S., 2022. Design, production, and validation of the biological and structural performance of an ecologically engineered concrete block mattress: a nature-inclusive design for shoreline and offshore construction. Integr. Environ. Assess. Manag. 18 (1), 148–162. https://doi.org/10.1002/ieam.4523.
Simon, H.A., 1996. The Sciences of the Artificial, 3rd ed. The MIT Press, Cambridge, MA, p. 231.
Søraa, R.A., Vik, J., 2021. Boundaryless boundary-objects: digital fencing of the CyborGoat in rural Norway. J. Rural. Stud. 87, 23–31. https://doi.org/10.1016/j.jrurstud.2021.08.015.
Steinke, J., Ortiz-Crespo, B., van Etten, J., Müller, A., 2022. Participatory design of digital innovation in agricultural research-for-development: insights from practice. Agric. Syst. 195, 103313. https://doi.org/10.1016/j.agsy.2021.103313.
Sundberg, J., 2014. Decolonizing posthumanist geographies. Cult. Geogr. 21 (1), 33–47. https://doi.org/10.1177/1474474013486067.
Tittonell, P., El Mujtar, V., Felix, G., Kebede, Y., Laborda, L., Luján Soto, R., de Vente, J., 2022. Regenerative agriculture—agroecology without politics? Front. Sustain. Food Syst. 6. https://doi.org/10.3389/fsufs.2022.844261.
Tomitsch, M., Fredericks, J., Vo, D., Frawley, J., Foth, M., 2021. Non-human personas: including nature in the participatory design of smart cities. Interact. Design Architect. 50 (50), 102–130. https://doi.org/10.55612/s-5002-050-007.
Tribaldos, T., Kortetmäki, T., 2022. Just transition principles and criteria for food systems and beyond. Environ. Innov. Soc. Trans. 43, 244–256. https://doi.org/10.1016/j.eist.2022.04.005.
Tsatsou, A., Frantzeskaki, N., Malamis, S., 2023. Nature-based solutions for circular urban water systems: A scoping literature review and a proposal for urban design and planning. Journal of Cleaner Production 394, 136325.
Tschersich, J., Kok, K.P.W., 2022. Deepening democracy for the governance toward just transitions in agri-food systems. Environ. Innov. Soc. Trans. 43, 358–374. https://doi.org/10.1016/j.eist.2022.04.012.
Turnhout, E., 2024. A better knowledge is possible: transforming environmental science for justice and pluralism. Environ. Sci. Pol. 155, 103729. https://doi.org/10.1016/j.envsci.2024.103729.
Turnhout, E., Neves, K., de Lijster, E., 2014. 'Measurementality' in biodiversity governance: knowledge, transparency, and the intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES). Environ. Plan. A 46 (3), 581–597. https://doi.org/10.1068/a4629.
Turnhout, E., Metze, T., Wyborn, C., Klenk, N., Louder, E., 2020. The politics of co-production: participation, power, and transformation. Curr. Opin. Environ. Sustain. 42, 15–21. https://doi.org/10.1016/j.cosust.2019.11.009.
van Bommel, S., Boonman-Berson, S., 2022. Transforming convivial conservation: towards more-than-human participation in research. Conserv. Soc. 20 (2), 136. https://doi.org/10.4103/cs.cs_29_21.
Van der Velden, D., Klerkx, L., Dessein, J., Debruyne, L., 2024. Cyborg farmers: embodied understandings of precision agriculture. Sociol. Rural. 64, 3–21. https://doi.org/10.1111/soru.12456.
van Veen, A., Helvoirt, B., 2024. De-Mooo-cracy! A Performative Experiment with a Cow-Human Citizen's Assembly: Evaluation Report. https://doi.org/10.13140/RG.2.2.35140.44168.
van Weeghel, H.J.E., Bos, A.P., Spoelstra, S.F., Groot Koerkamp, P.W.G., 2016. Involving the animal as a contributor in design to overcome animal welfare related trade-offs: the dust bath unit as an example. Biosyst. Eng. 145, 76–92. https://doi.org/10.1016/j.biosystemseng.2016.02.015.
van Weeghel, H.J.E., Bos, A.P., Jansen, M.H., Ursinus, W.W., Groot Koerkamp, P.W.G., 2021. Good animal welfare by design: an approach to incorporate animal capacities in engineering design. Agric. Syst. 191, 103154. https://doi.org/10.1016/j.agsy.2021.103154.
Verdouw, C., Tekinerdogan, B., Beulens, A., Wolfert, S., 2021. Digital twins in smart farming. Agric. Syst. 189. https://doi.org/10.1016/j.agsy.2020.103046.
Vermunt, D.A., Negro, S.O., Van Laerhoven, F.S.J., Verweij, P.A., Hekkert, M.P., 2020. Sustainability transitions in the agri-food sector: how ecology affects transition dynamics. Environ. Innov. Soc. Trans. 36, 236–249. https://doi.org/10.1016/j.eist.2020.06.003.
Vermunt, D.A., Wojtynia, N., Hekkert, M.P., Van Dijk, J., Verburg, R., Verweij, P.A., Wassen, M., Runhaar, H., 2022. Five mechanisms blocking the transition towards "nature-inclusive" agriculture: a systemic analysis of Dutch dairy farming. Agric. Syst. 195, 103280. https://doi.org/10.1016/j.agsy.2021.103280.
Walthall, B., Vicente-Vicente, J.L., Friedrich, J., Piorr, A., López-García, D., 2024. Complementing or co-opting? Applying an integrative framework to assess the transformative capacity of approaches that make use of the term agroecology. Environ. Sci. Pol. 156, 103748. https://doi.org/10.1016/j.envsci.2024.103748.
Watts, V., 2016. Smudge this: assimilation, state-favoured communities and the denial of indigenous spiritual lives. Int. J. Child Youth Family Stud. 7 (1). https://doi.org/10.18357/ijcyfs.71201615676. Article 1.
West, S., Haider, L.J., Stålhammar, S., Woroniecki, S., 2020. A relational turn for sustainability science? Relational thinking, leverage points and transformations. Ecosystems and People 16, 304–325.
Wolfert, S., Verdouw, C., van Wassenaer, L., Dolfsma, W., Klerkx, L., 2023. Digital innovation ecosystems in Agri-food: design principles and organizational framework. Agric. Syst. 204, 103558. https://doi.org/10.1016/j.agsy.2022.103558.
Yaneva, A., 2009. Making the social hold: towards an actor-network theory of design. Des. Cult. 1 (3), 273–288. https://doi.org/10.2752/174967809X12556950208826.
Youn, H., Baek, J.S., 2024. Assemblage-based stakeholder analysis in design: a conceptual framework through the lenses of post–anthropocentrism. CoDesign 1–22. https://doi.org/10.1080/15710882.2024.2358966.