Agricultural Systems 191 (2021) 103154

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Good animal welfare by design: An approach to incorporate animal capacities in engineering design

H.J.E. van Weeghel [a,*], A.P. Bos [a], M.H. Jansen [b], W.W. Ursinus [c], P.W.G. Groot Koerkamp [b]

[a] Livestock & Environment, Wageningen Livestock Research, Wageningen University and Research, P.O. Box 338, 6700, AH, Wageningen, the Netherlands
[b] Farm Technology Group, Department of Plant Sciences, Wageningen University and Research, P.O. Box 16, 6700, AA, Wageningen, the Netherlands
[c] Office for Risk Assessment & Research (BuRO), Netherlands Food and Consumer Product Safety Authority (NVWA), P.O. Box 43006, 3540 AA, Utrecht, the Netherlands

HIGHLIGHTS

- We propose a novel approach to include positive animal welfare in engineering design.
- Animal Capacities in Design is an approach for sustainable animal production systems.
- The Brief of Capacities design tool gives an overview of animal capacities.

ARTICLE INFO

Editor: Dr. Guillaume Martin

Keywords:
Positive animal welfare
Animal capacities
Engineering design
Reflexive interactive design (RIO)
Brief of capacities
Sustainable development
Animal production systems

ABSTRACT

CONTEXT: In systems design for livestock husbandry, the tendency is to focus on technical measures and to control the behaviour of animals in order to reduce complexity and make system functioning predictable, thereby often treating animals as agricultural objects. However, treating animals as agents and providing in opportunities for animal agency – defined as being able to control the (social and physical) environment through choice and decision-making by the animal based on individual preferences and demands – is recognized as being important in having positive experiences and in achieving good animal welfare. The opportunity of an animal to use one's capacities to control one's environment is important for the animal herself, and, at the same time, can contribute to the functioning of the system.
OBJECTIVE: We propose a design approach, Animal Capacities in Design (ACiD), that enables engineers of livestock systems to include animals' capacities into the *design process* and promotes more animal agency in the *final design*.
METHODS: The ACiD approach, which was partly developed through a series of workshops with engineers, involves the systematic and structured consideration of animal physiological, morphological and behavioural capacities as well as system functions and sub-functions in order to identify animal-based solutions.
RESULTS AND CONCLUSIONS: ACiD consists of different parts: a Brief of Capacities (BoC), BoC user guidelines, and BoC application instructions. The BoC is a design tool that provides an overview of capacities of a specific animal species, further specified and ordered by means of capacity attributes that provide additional information to understand and deploy these capacities in the design process. An attitude shift towards 'providing agency' instead of the currently dominant engineering paradigm of 'taking care of' is needed for successful application. ACiD stimulates this change in attitude through the inclusion of animal agency in the design goals, the set-up of an overview of requirements that includes positive welfare requirements, and it challenges engineers to (re) define functions in such a way that they allow for non-technical solutions enlarging the solution space for more active animal involvement.
SIGNIFICANCE: The ACiD approach facilitates and creates accessibility to relevant biological information for designers during the design process and aims to integrate the animal and her capacities in new and sustainable designs of livestock husbandry. The promise is a mutual beneficial relation between human goals and good animal welfare in future livestock husbandry systems.

* Corresponding author.
E-mail address: ellen.vanweeghel@wur.nl (H.J.E. van Weeghel).

https://doi.org/10.1016/j.agsy.2021.103154
Received 18 August 2020; Received in revised form 12 April 2021; Accepted 16 April 2021
Available online 11 May 2021

1. Introduction

Agricultural systems, both arable and livestock, are essentially biological systems managed by humans. The leading paradigm in agriculture since mid 20th century is one of increased efficiency, higher volumes and predictable output. A challenge in designing livestock production systems in a systematic way is dealing with the unpredictable and uncontrollable behaviour of the animals living in the system. The dominant coping mechanism of this challenge is to eliminate as much variation as possible by standardization, shielding the system and the animal in it from outside perturbations, and by increasing levels of control. Technology and artefacts are human interventions that 'bring order, predictability, and control over the future' (Shahare, 2015). The tendency to focus on technical measures for (biological) challenges resulted in top-down controlled animal production systems (Bos et al., 2003; Mitsch and Jørgensen, 2003), characterized by a high level of human control over an ever increasing number of parameters and the treatment of animals as objects rather than as living and social beings with their own goals, needs and interactions (human-animal, animal-animal, animal-environment). Bos et al. (2003) call this the 'unidirectional control approach' in which they pose that 'nature is principally non-cooperative, unless it is forced, therefore in order to reach certain goals controls have to be added'. In animal production systems, humans have far-reaching, often technologically mediated, control over many system features such as distribution, availability, and variation of food and water; quantity and complexity of space; and structure and diversity of animal social groups (Mellor, 2016).

When referring to animals in production system it is custom to refer to as 'it' unless the relationship is personal (like a pet that has a name). We believe however that the way animals are referred to has an effect on the process and outcome of design processes; it helps designers in their task to design for animals as sentient beings with their own goals, needs and interactions. It is therefore that throughout this paper we refer to animals using personal pronouns. Since the majority of animals in production systems are female we use female personal pronouns.

Good animal welfare is of growing importance for animal production systems in countries across the world; important for the animals themselves, as sentient beings, as well as for society. The high level of human control and numerous technological interventions that are present in current animal production systems however results in a low level of freedom for animals to make their own choices and control their environment (Mellor, 2016) in order to produce results that are desired for themselves (Manteuffel et al., 2009; Špinka and Wemelsfelder, 2011). The notion that animals have such choice and control is called animal agency. Animals have a strong intrinsic motivation to perform all kinds of behaviour (Bracke and Hopster, 2006) and have a strong desire to engage and interact with their environment. If an animal cannot respond to such intrinsic motivation or when she cannot control a situation or is unable to adapt to it, she experiences distress (Bassett and Buchanan-Smith, 2007), which can lead to negative welfare states such as apathy (Wood-Gush and Vestergaard, 1989), fear or anxiety (Rodenburg and Koene, 2007) and undesired behaviours like feather pecking in laying hens (de Haas et al., 2014) and tail biting in pigs (Ursinus et al., 2014). Possessing control, and thus having agency, has – from a biological and psychological perspective – a positive effect on the animal and is not only desirable but a necessity for good animal welfare (Leotti et al., 2010; Sambrook and Buchanan-Smith, 1997; Yeates, 2017).

To operationalize animal welfare in systems design, Bracke et al. (1999) use the needs-based approach in which needs (e.g. need for food, sex, social contact) that are intrinsically relevant for the animal are listed. This approach provides insight into "what matters from the animal's point of view". Using the needs-based approach when designing animal production system helps to avoid negative experiences for the animal and aids in achieving basic welfare based on physiological and ethological needs. However, good animal welfare goes beyond the mere absence of negative experiences and fulfilling the animal's needs; it also specifically includes positive experiences. Mellor (2012) refers to this as 'positive welfare'. Positive welfare recognizes that an animal can have positive emotions and moods, such as pleasure, confidence, feeling secure, goal-directed engagement, curiosity, vitality, playfulness, calmness, and contentment. An important aspect achieving a state of positive welfare is for the animal to have agency; to be able to make choices and thereby exert control over her environment. Thus, achieving good animal welfare through design is more than fulfilling animal needs, it should also provide in opportunities to experience positive welfare states, which can be achieved through agency. When animals possess agency, the animal herself – as an agent – has the ability to enhance her welfare through influence and control over her environment (Wemelsfelder, 1997).

Design projects applying Reflexive Interactive Design (RIO, Dutch Acronym) – an interactive structured design approach to contribute to system innovation (Bos et al., 2009; Groot Koerkamp and Bos, 2008; Puente-Rodríguez et al., 2019; Romera et al., 2020; van Weeghel et al., 2016) –, show that the needs of animals can be successfully taken into account when designing complex animal production systems. These RIO-projects predominantly aim at fulfilment of animal needs of the animal. In the RIO approach the animal is considered as a stakeholder, but does not has the structure and tools to consider the animal as a potential agent who can actively contribute to the animal production system. This limits the opportunities for enabling animal agency within this approach (van Weeghel et al., 2016).

An approach to enable agency, stemming from the social sciences, is the capabilities approach (CA) which is a theoretical framework for the conceptualisation of human welfare (Nussbaum, 2001; Sen, 1999). CA claims that the freedom, for humans, to achieve well-being is vital and well-being has to be understood in terms of people's capabilities, that is, "their real opportunities to do and be what they have reason to value" (Robeyns, 2011). We prefer using 'capacity', instead of 'ability' or 'capability', because the latter imply a certain level of performance, suggesting that an organism does something *well (enough)*. Capacity refers to the *potential* of the organism, regardless of how well the organism fulfils this potential with performed action. In this research we define animal capacity as: "The ability of an animal to perform actions or maintain/change their state through their physiology (internal processes), morphology (external physical features) and/or behaviour (actions or inactions of animals (individuals and groups) to internal and/or external stimuli) (cf. (Johnson and Raven, 2001)). Capacity is emergent at the organism level, as opposed to, e.g., the atomic, molecular, cellular or organ level (Reece and Campbell, 2011). Animal capacity is a theoretical concept, based on empirically identifiable characteristics which are dependent on internal motivation and on social and physical external conditions for realisation (Fig. 1). Capacities are present, albeit (in)visible or latent, within the individual organisms. They are expressed in the environment where they can become meaningful for both the animal and its surroundings. As argued by Oosterlaken (2013), it seems useful to integrate CA to promote agency in design, however, a systematic way to do this does not yet exist. Not for humans, and certainly not for (production) animals.

An important principle of CA is to treat individuals, animals or humans, as active participants who value opportunities to make choices based on the individuals' own motivation, instead of passive beings who should be taken care of (Oosterlaken, 2013; Sambrook and Buchanan-Smith, 1997). The classical approach of agricultural engineers is to think in terms of 'taking care of animals' and to design facilities 'for' animals. Animals possess a variety of capacities, ideally, engineering design (ED) incorporates those capacities that are motivationally-driven, i.e. linked to a specific need. Design can motivate an animal to engage in activities that are meaningful for the animal herself as well as other system goals (Desmet and Pohlmeyer, 2013).

In this paper, we present the groundwork of a systematic design approach, called ACiD: Animal Capacities in Design. ACiD serves as an alternative to the classical approach of agricultural engineering and

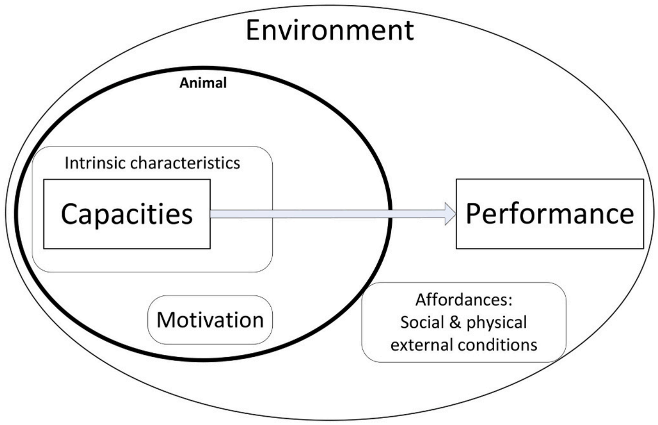

Fig. 1. Animal capacities, the performance of capacities is dependent on individual characteristics, motivation and social and physical external conditions.

supports designers to think in terms of 'providing possibilities' for animals to take care of themselves, and by doing this to contribute to fulfilling system functions at the same time.

While we recognize that farmers are often part of interactive participatory design processes of new livestock systems (Martin, 2015; Meynard et al., 2012; Moraine et al., 2017) we do not consider them to be designers in the ACiD approach. We consider designers to be those who are trained in engineering and therefore do not necessarily have a background in biology or have practical experience with the animals involved. Since biological knowledge can be highly useful when presented and used at the right moment in ED (Sartori et al., 2010), our approach is a systematic guidance to enable designers to integrate biological knowledge into the ED process. It helps designers to consider the animal and her capacities as a potential source to fulfil functions in the design process and facilitates in overcoming 1) lack of knowledge of the animal, 2) bias towards current knowledge or practice in ED resulting in being blind for the non-obvious, previously unused behaviour, 3) heuristics and chance because of a lack of systematic guidance, 4) lack of confidence in the specific capacity or behaviour of the animal as a solution, and/or 5) fear for the unknown and unpredictable variation. The ACiD approach enriches existing engineering design methods (in this paper we use the RIO method) by adding biological knowledge of the animal in the form of capacities. The objective of ACiD is twofold, to enable engineers to incorporate animal capacities in the *design process* and to promote more animal agency in the *final design*. The approach makes relevant biological information accessible to engineers, enabling them to integrate the animal and her capacities in the design of livestock systems.

We start with a description of the ACiD approach and its parts, and how we came to a first draft of a capacities overview. Then we describe how we used engineer work sessions to further develop and validate the ACiD approach. In the results we present the final capacities overview – called the final Brief of Capacities. We also describe how to use and apply the Brief of Capacities and which adjustments to some of the engineering design steps are necessary to be able to involve the animal as an agent and to come to animal capacities-based solutions. In the discussion we discuss the most striking insights obtained in the engineer work sessions.

2. Materials and methods

2.1. Animal capacities in design approach

The Animal Capacities in Design (ACiD) approach aims to incorporate capacities of animals in the design of sustainable livestock husbandry systems and consists of several parts. ACiD has three parts 1) the Brief of Capacities (BoC), 2) BoC user instruction and 3) BoC application instruction. The first part, the BoC, is a design tool that provides an overview of capacities (ordered into categories) of a specific animal species and gives additional information to understand and deploy these capacities in the design process. The BoC enables engineers to enlarge the (technical) solution space and to consider the biological domain in a structured manner. At the same time it is a heuristic tool to trigger the mind. The overview is called a Brief of Capacities because its structure resembles that of the Brief of Requirements commonly used in ED, which is an overview of the requirements for the system that will be designed. The second part of ACiD is the BoC user instruction, which – briefly – explains how to deploy the BoC in order to generate animal involved solutions. The third part, the BoC application instructions, gives direction on how to apply the BoC in ED and the necessary adjustments of the ED design steps to be able to incorporate animals – as agents - in the design process.

ACiD can be used as an add-on in any structured design approaches, such as ED or derivates thereof, as long as the elementary design steps are present and include: design goals, (quantitative) requirements, system functions, solutions and selection and compilation of solution to form the design. The RIO approach is used in this paper, which is an adapted version of ED (Siers, 2004). For a description of the RIO design process and most recent insights see van Weeghel et al. (2016), and for an overview of projects that applied RIO and the results in practice see Elzen and Bos (2019).

2.1.1. Meta criteria of ACiD

The ACiD approach is considered successful when it guides designers in the application of animal capacities in design solutions, while at the same time increasing the chance that livestock animals strengthen their agency within this (designed) environment. An important normative objective is that this contributes to good animal welfare – including positive welfare – for the animals involved, and preferably introduces none or few trade-offs with the needs and requirements of other stakeholders. In other words, the animal should be internally motivated to fulfil her needs and as a result express or perform certain desired capacities; the capacities become functional for the system when being applied for system goals and functions.

To achieve these objectives, the following meta criteria apply for ACiD: 1) it helps to find (novel) solutions wherein animals are involved (animal-based solutions), 2) it is understandable for engineers with varying levels of biological knowledge, and 3) the BoC as a tool is logical, readable and usable. Therefore the BoC should include the following information: a) a clear overview and description of animals' capacities, b) the possible result(s) of the capacity, c) the variation in the way the capacity can be expressed, and d) the external conditions to perform the capacity in the environment.

2.1.2. Elementary biological content of the brief of capacities

The Brief of Capacities is an overview of the capacities of an individual of a specific animal species, including relevant biological information of a capacity, so as to be able to incorporate animal capacities in ED. While giving a full overview and detailing of the capacities of a specific animal species is not the purpose of the current paper, some biological content is needed in order to adequately set-up and explain the BoC. Therefore, we use a BoC with elementary – not exhaustive – biological content. A workable BoC should have enough biological content and variation to perform the initial set-up of the BoC structure. A first version of a BoC (BoC 1.0) was drafted based on the BoC meta criteria, the findings of the biological content data search and the previous experience with RIO and redesign projects.

There are four categories in which animal capacities can be subdivided: 1) ethological/behaviour, 2) autonomy/physiology, 3) cognition/mentally, and 4) morphology (Reece and Campbell, 2011). For the initial set-up of the BoC, biological information found in animal science literature including ethograms, and expert consultations were used.

2.1.3. Engineer work sessions

Engineer work sessions (EWS) were organised to further develop and validate the ACiD approach. The intended result of the EWS was threefold: 1) improved versions of the BoC structure, 2) user instructions for the autonomous use of the BoC as a tool, and 3) BoC application instructions in ED, including the necessary conditions in the overall design process for the successful application of ACiD.

Three consecutive EWS were held, starting with a session with participants with a low level of engineering experience, followed by sessions with participants with more experience and so on (Table 1). After each session, the BoC was updated to a new version and implemented in the next session. As such we aimed at gaining more insight into what engineers at different levels of experience needed in order to involve the animal and her capacities in the design process and to think of animal-based solutions. Every EWS had the same facilitator and an observer present. In each EWS the same design assignment was presented. In short, the design assignment asked the participants to formulate functions and generate solutions for the following objective "A healthy living environment for pigs anytime of the year". In the first and second EWS the design assignment consisted of three consecutive assignments that built upon the previous one, starting without any imposed animal focus and ending with the direct question to come up with animal-based solutions only: 1) An open question to formulate functions and generate solutions; 2) An additional question to generate more solutions that involve the animal; and 3) the provision of the BoC and BoC application instructions in order to, more systematically, generate animal-based solutions. In the third EWS the BoC was directly given and participants were asked to do the assignment individually at first. After the individual exercise, the assignment was repeated in groups. This resulted in the participants having an intensive brainstorm on the structure of the BoC and application of ACiD in the design process.

Table 1
Overview of the set-up and results of three engineer work sessions (EWS) that were organised to further develop the BOC as a tool and to improve the BOC application instructions. V=Version.

	EWS1	EWS2	EWS3
Objective	Test and develop BoC Set-up BoC user instructions Observe BoC application	Test and develop BoC Set-up BoC user instructions Observe BoC application	Validation of BoC Validation of BoC user instructions Validation of BoC application instructions
Participants	BSc and MSc students ($n = 4$) who successfully followed the courses engineering design and biosystems design at Wageningen University	PhD students ($n = 3$) of the Farm Technology Group of Wageningen University	Engineer professors of the Wageningen University and engineer professionals (n = 4) from the agri-practice
Input	Design assignment BoC 1.0 BoC application instructions 1.0	Design assignment BoC v2.0 BoC application instructions v2.0	Design assignment BoC v3.0 BoC user instructions BoC application instructions v3.0
Output	Filled design assignment Evaluation of the BoC	Filled design assignment Evaluation of the BoC	Filled design assignment Evaluation of the BoC
After synthesis & analysis	BoC v2.0 Preliminary BoC user instructions BoC application instructions v2.0	BoC v3.0 Preliminary BoC user instructions BoC application instructions v3.0	BoC v4.0 BoC user instructions v4.0 BoC application instructions v4.0

3. Results

The ACiD approach is essentially a package of different parts and consists of the final BoC (3.1), BoC user guidelines (3.2) and BoC application instruction for the different steps of an engineering design method (3.3). The three parts are described separately in the next paragraphs.

3.1. Final BoC

The experiences and insights derived from setting up BoC version 1.0 and the three EWS leading to BoC version 4.0, were used to finalise the BoC. Basically the BoC is a grid, with on each row one capacity and in the columns a further specification for that capacity, ordered by different capacity attributes. The most fundamental change of the final BoC structure compared to earlier versions is the capacity attributes that are used to describe the capacities. The final BoC gives an overview of the capacities of – in this case – the pig and all the necessary information needed to explain the capacity according to different capacity attributes. The capacity attributes are: description, specifications, behaviour, associated needs, category, activity type, conditions (external and internal), and variation. The final BoC is presented in Table 2 and the capacity attributes are explained in Table 3. In the BoC the terms 'object' and 'subject' are used, they differentiate between the living (subjects) and non-living (objects). Subjects do not have to be the same species and can be humans as well. Objects can refer to permanent hardware but also to non-living material that is present only temporary.

As defined earlier, a capacity is"the ability of an animal to perform actions or change/maintain their state through their physiology, morphology and/or behaviour." Following this definition, the capacity is formulated from the perspective of the animal. For example, the capacity to move is formulated as 'locomote oneself' rather than 'animal moves'. The capacity is formulated as a function – a verb plus noun – in order to align the functional analysis step in ED with the capacities in the BoC (3.3.3). The capacity formulation is placed in the first column of the grid.

The *description* attribute is used to elaborate on the capacity formulation, going beyond the abstract functional style of verb + noun. This column is therefore less practical to bridge with ED, because it is less technical, but does provide essential information to specify the meaning of the capacity.

The *specification* attribute describes how the capacity could be achieved and includes: body parts used, direction (of movements), and specific skills such as language. The specification attribute is set-up in such a way that it can be put behind the capacity formulation and make a logical sentence. For example, 'move object/subject' - 'with paw'; and 'interact with object/subject' - 'through olfaction'.

The *behaviour* attribute provides examples of the capacity when performed. These behavioural examples can be found in ethograms in animal science literature. Since the behaviours included are examples, the set is not exhaustive. They explain in more biological terms what the capacity can lead to when put into practice: the performance. The disadvantage of inserting this attribute is that the mind is focused on these 'well-known' possibilities and perhaps other possibilities are overlooked or are not thought of. For example: maybe pigs can be taught sign language by using ears and tail, but this will not emerge as an option if the mind is already focused on communication by mouth.

To make a connection between the capacity and the relevance for the animal the *associated needs* attribute was constructed. It does not directly answer how important it is for the animal or how motivated the animal is to perform the capacity, but it does indicate which need(s) are predominantly related. Only the most, directly, related needs are included in the BoC.

The *category* attribute differentiates the activity into three different categories: 1) ethology (including the category: cognition/mental) (E), 2) physiology (P), and 3) morphology (M). Ethological behaviour is

Table 2
Overview of the brief of capacities of the pig structured by capacity (rows) and capacity attributes per capacity (columns).

Capacity	Description	Specifications	Behaviour	Associated needs	Category	Activity type	Conditions			Variation
							External conditions		Internal conditions	
							Physical	Social	Physical	
Locomote oneself	animal moves from point A to point B	forward, backward, sideways, upward, downward	walk, hop, pivot, gambol, glide, roll, jump, play, swim, climb	locomotion	E	action	space, surface, object	subject (in case of group performance)	locomotory apparatus	speed
Manipulate object/ subject				exploration, foraging	E		object to manipulate	subject to manipulate		
	animal gains knowledge	with snout, mouth, tongue and teeth	bite, chew, grasp, nibble, suckle, graze, root			sense (olfactory, auditory, gustatory, touching, visual)			facial apparatus	processing speed
		with paw(s)	scratch, stand on			sense (olfactory, auditory, touching, visual)			locomotory apparatus	processing speed
	animal manipulates object/ subject	with snout, mouth, tongue and teeth	bite, chew, grasp, nibble, suckle, graze, root			action			facial apparatus	strength, force
		manipulate with paw(s)	scratch, stand on			action			locomotory apparatus	strength, force
Express oneself	animal indicates intention, animal expresses emotion, communication with object/ subject			social, safety	E	action	–	–		
		verbally/vocally	grunt, squeal, vocalization						vocal instrument	volume, duration
		non-verbally/ with body signals	body posture, positioning ears/tail, back arch, tail wagging						body part(s)	shape
Generate heat	residual heat from metabolic processes is generated, or additional sensible heat is produced	through glycolysis (oxidation of glucose)	physical effort, metabolism	thermoregulation, health	P	process, action	food, space		gastrointestinal tract, locomotory apparatus	body weight, production rate
Transfer heat	energy from the body is transferred to the environment or vice versa			thermoregulation	P				integumentary system	temperature
		through radiation (heat emission from skin to air)	radiation			process	conductive environment			
		through conduction (heat transfer through skin contact)	huddle	social		action	objects	subjects		
		through cooling down	wallowing, water contact, panting, sweating, contact cool surface	health, body care		action	mud, water			
Exert weight	animals puts pressure or weight on something	gravity	standing, pushing	–	M	–	surface			weight, pressure, strength

Table 3
Explanation of the capacity attributes of the brief of capacities.

Capacity attribute	Description
Capacity	Capacities are formulated as a function, a verb plus a noun, from the perspective of the animal
Description	The description describes the capacity more elaborate than the 'verb + noun' construction. So, 'locomote oneself' is described as the animal moves from point A to point B
Specifications	Here is described how the capacity is achieved; which body parts are used, in which directions the capacity can take place, and specific skills. So for 'locomote oneself', the movement can go forward, backward, sideways as well up- and downwards and 'express oneself' is verbally/vocally
Behaviour	The different behaviours that give expression to the capacity, but are not limited to the examples provided in the Brief of Capacities
Associated needs	There are 14 needs identified for pigs: social, safety, foraging, exploration, resting, maternal, reproduction, satiation, thermoregulation, health, body care, respiration, excretion, and locomotion (Bracke et al., 1999; Wageningen UR Project team 'Animal Oriented Design for Pigs', 2012)
Category	There are three categories: ethological (includes cognition) (E), physiology (P), and morphology (M)
Activity type	There are three activity types: sense, process, and action
Conditions	The conditions necessary to perform the capacity. Divided into internal conditions: the animals' physical condition, and external conditions: such as physical environment and social conditions
Variation	Physical and biological characteristics that indicate the variation of the capacity, such as speed, weight, temperature, duration, shape, force, processing speed, complexity, volume

behaviour that the animal can express deliberately, such as locomotion, foraging, reproductive and resting behaviour. Mental activities are the activities of thinking, understanding, learning, and remembering. Cognitive skills are the 'mechanisms by which animals acquire, process, store and act on information from the environment' (Shettleworth, 2001). Physiology comprises visceral functions that are controlled automatically, e.g. the cardiovascular, digestive, respiratory, immune and excretory system. Morphology is the external spatial form and state of the animal, the animals' habitus. The category column distinguishes voluntary behaviour (E) and autonomous states (P&M) on an abstract level. There is a difference in applying a capacity that is based on non-autonomous behaviour, or on autonomous processes, since behaviour needs to be elicited when needed, while autonomous processes and habitus are just 'present' or not at a certain point in time.

The *activity* attribute differentiates the capacity into three categories: 1) sensing, 2) processing, and 3) acting. Sense is the state where information is acquired and generally used for cognitive processes by the animal. Thereafter the acquired information is processed, which entails memorization, retrieval and decision-making processes as well as autonomous internal processes such as digestion and emission of heat and carbon dioxide. After processing, the animal can express herself by performing an action. This differentiation into activity types is made to explain – in engineering terms - the different stages at which a capacity can be present and clarifies the sequence to follow. For an action to take place it is – usually – preceded by a sensing activity in which information is acquired. For example, if one wants to provide a differentiated area specially adapted for foraging behaviour which can be entered by a one-way gate, the animal needs to be able to find the gate and be willing to use it. Therefore the preceding steps before the action need to be acknowledged and consist of acquiring the necessary information (sensing) and processing this. Some capacities are directly satisfying for the animal, and other capacities are a means to achieve another goal.

Going from capacities to their actual expression in performed behaviour depends on specific internal motivation and environmental (social and physical) conditions, and this information can be found in the *conditions* attribute. Internally, if the animal is physically able to give expression to the capacity, for example to be able to 'locomote oneself' the animal needs to possess a functional 'locomotory apparatus'. External conditions include the physical environment, in order to locomote space and surface are needed, and may include the social environment as well: in order to interact with another living entity, another living entity needs to be present.

One of the needs for information on a capacity is how much an animal can express the capacity. For instance: how fast, how long and how far an animal can locomote. In the *variation* attribute the different types (physical and biological characteristics) of variation of the capacity are specified, such as 'speed' for locomotion, but without further quantification.

3.2. BoC user instructions

The engineer work sessions showed, through the application of the BoC, two approaches to generate solutions that involve the animal. In the first approach, the BoC was queried in search of animal capacities that could fulfil the defined functions, making the link between the engineering and the biological domain. In the second approach, the BoC was used as a heuristic device that helped the designer to think of new ideas to incorporate animal capacities. As such, the BoC functioned as an aid by offering an overview of possibilities through which the engineer could transpose biological information to the engineering domain. Reading, or scanning the BoC triggered the mind of the designer to search and design for alternative biological solutions, outside the technical realm.

In the application of the BoC, the capacity formulation appeared to be the most important entry. The functions were (re)defined through iterations with the BoC (see 3.3.3 functions) and were therefore – to a certain extend – analogous with the capacities. There were several attributes that could be used, such as the *specification* attribute when specific body parts or skills were needed (e.g. paw, vocalization, olfaction), the *behaviour* attribute when a specific behaviour was necessary (e.g. mounting, biting), and the *associated needs* attribute for the search on capacities that were associated with certain needs (e.g. thermoregulation, excretion). These attributes could be helpful, but further application of the BoC must show what works and how.

3.3. BoC application instructions

The following design steps are usually part of an engineering design method (see Fig. 2 for a visualisation of these steps within RIO): A) Goals and key challenges, B) System analysis, C) Key actors and analysis of needs, D) Briefs of requirements, E) Design goals, F) Key functions, G) Morphological chart, H) Design concepts and N) Detailed proposals. The BoC is applied in the function formulation (step F) and in the generation of solutions (step G). However, to successfully apply the (more encompassing) ACiD approach in the design process some adjustments and considerations to other design steps are needed as well (Fig. 2). All of these are elaborated below.

3.3.1. Goals (step A and E)

During the formulation of the design goals (steps A and E), it is crucial to embed animal agency in the system to be designed. To be able to consider the animal as a contributor in design, this mental shift – from animals with a passive role towards animals with an active role - should be made explicit at the very beginning. Therefore, at least two goals are formulated, a production goal and an additional goal specific for this ambition, e.g. "Animals in the production system have (some degree of) agency, i.e. animals can make their own choices and act upon them". Emphasizing the animal's role and thereby expanding the focus from a solely technical point of view to a view which includes animal capacities will lead to "the formulation of a different set of design criteria and therefore fundamentally different designs" (Hall and Lima, 2001). As an example: in the 70s of the twentieth century the design goal of a tiger enclosure was 'to display a tiger' and in the 90s the goal was formulated as 'create an optimal habitat for a tiger' (Hall and Lima, 2001). Leading

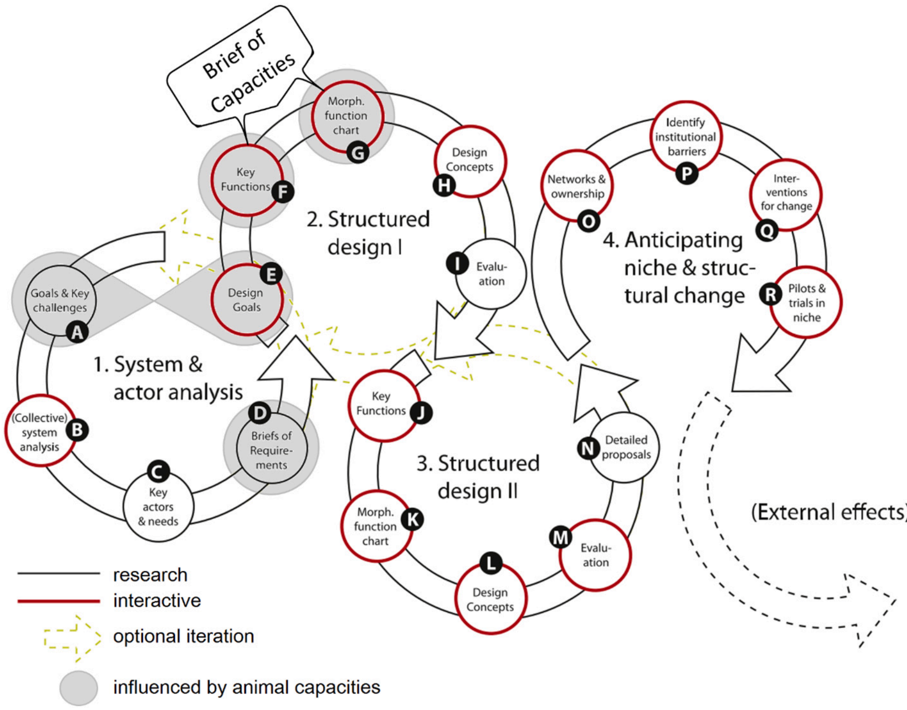

Fig. 2. The four loops of the reflexive interactive design (RIO) approach as applied in the well-fair eggs project (van Weeghel et al., 2016), with the design steps A to R as circled activities, either performed as research (in black) or in interaction with stakeholders (in red). Application of the brief of capacities is in step F & G. To sucessfully apply animal capacities in design (acid approach) adjustments to steps A, D, E, F & G are needed. morph. = morphological.

to two fundamentally different designs and enclosures for tigers.

3.3.2. Requirements (step D)

The BoC strives to show as much of the animal potential as possible and the capacities identified do not contain (implicit) compromises with other considerations than the animal. However, there can be potential solutions that are undesired from an animal's point of view. Therefore, when constructing the Brief of Requirements – which is an overview of all the requirements that the newly designed system has to meet in order to meet the animals' needs - also requirements with respect to animal agency should be included. These requirements are important to consider for two reasons, 1) to make sure no (unintentional) harm to the animal is being done, and 2) to make sure that the initial goal of more animal agency is being achieved. For example, the following requirement could be added: "the animal has multiple options to choose from". The Brief of Requirements specifies strict and optional conditions and has a different purpose in the design process than the BoC which is a heuristic instrument. Including such requirements in the Brief of Requirements stimulates the use of the BoC for its intended purpose: promote animal agency, not the mere utilization of animal capacities.

3.3.3. Functions (step F)

In the function analysis step, the (sub)system to be designed is defined in precisely formulated functions. Finding suitable and effective solutions depends on a detailed function analysis and precise function definition. Function analysis facilitates the generation of solutions, but 'are not ends in themselves' (Pahl and Beitz, 2013). However, the function analysis is a critical step and an intervention to incorporate animals in the solutions. It is in the function analysis that the focus was on the technical domain, but is now broadened with the biological domain. To enable incorporation of animal capacities: 1) abstraction and 2) decomposition of functions are needed, which is described hereafter.

3.3.3.1. Function abstraction. Traditionally, ED focuses on finding a technical solution for a (technical) problem. Most often, this technical focus is reflected in the way functions are defined, by assuming (implicitly) that solutions for these functions will have to be added to the system (instead of already being present). In case of animal production systems this can be seen in function definitions that assume that either humans or technology have to fulfil a certain need or activity. For instance: animal thermal comfort can be fulfilled with a function such as 'control temperature'. However, functions need to be defined in such a way that it includes possibilities to let the animal fulfil the function. These functions should enable not only 'for the animal' but moreover 'by the animal' solutions. There are two ways to widen the scope of the function definition: a) through semantics, and b) by interaction with the BoC.

a) Semantics

Word use is critical in formulating functions. Finding the best fitting description to define the task (*what* needs to be done) is not straightforward. Function definitions (at least) contain a verb and a noun. Changing the verb or noun may enlarge the solution space to include the animal as contributor. Usually, terms like 'control' and 'do/make' are used, e.g. 'control temperature'. However, these words do not necessarily mean that humans and technology should realise this function. In practice, one is often (unconsciously) biased to look for technical solutions and the choice of verbs strongly determines the solution scope and space. Alternative verbs that broaden the scope are e.g. 'provide', 'facilitate', 'enable', 'stimulate', 'entice', 'elucidate'. In this way the function 'control temperature' could transform in 'facilitate thermal comfort', which describes what needs to be done in a less controlling manner and leaves more room to find animal-based solutions.

b) Interaction with BoC

There is still a conceptual gap between abstracted functions in the function analysis and the animal capacities in the BoC. Design processes are iterative and in the function analysis several iterations between the function formulation and the BoC need to be made. Switching back and forth between functions and the capacities formulation of the BoC will rearrange and change the formulation. The capacities in the BoC trigger the engineer to reformulate and rearrange functions differently and help to create the necessary mind-set. After abstraction, and in interaction with the BoC, functions should represent the precise intention and make the connection with the biological domain.

3.3.3.2. Function decomposition. Decomposing functions into sub-functions facilitates the subsequent search for solutions. Sub-functions can be further decomposed into sub(*sub*)functions until the necessary system level is achieved. Breaking down functions into detailed sub-functions gives more specific intervention points, and results in a wider range of possible solutions, including specific animal behaviours (van Weeghel et al., 2016). The combination of these sub-functions are represented in a simple and clear function structure (Pahl and Beitz, 2013). In Table 4 we show an example of a function structure for the function: facilitate thermal comfort. Function decomposition enables the creation of composed solutions, in which both technical and biological partial solutions can play a role.

3.3.4. Morphological chart (step G)

A morphological chart is an overview of the functions (the *what*) and their solutions (the *how*). Normally this overview has no distinction in solutions, but, to ensure animal-based solutions we propose to divide the morphological chart into technical and biological solutions. The morphological chart could therefore be split up into three categories of solutions: 1) technology-based, 2) human-based, and 3) animal-based (van Weeghel et al., 2016). Category one and two can be filled through the conventional engineering method, the animal-based category, can be found through the application of the BoC. In Table 5 an example of a morphological chart for the function 'facilitate thermal comfort' is given.

4. Discussion

This research is, to the best of our knowledge, the first within the design of sustainable livestock husbandry systems domain that attempts to offer a structural approach for promoting animal agency in the final design and animal contribution to the system functioning. This paper describes ACiD as an approach and is not applied nor validated in a practical situation or case yet. Therefore, the meta criteria (2.1.1.), such as 'generating novel animal incorporating solutions', 'being understandable' and 'readable for engineers', are not yet evaluated for success. In the discussion we go into more detail about the experiences of the engineers working with ACiD in the engineer work sessions (4.1), the conceptual construct of capacities (4.2), and the implications for the BoC and further research (4.3).

4.1. Working with ACiD

In the engineer work sessions (EWS) the struggle with the formulation of functions became apparent. All of the initial functions – without animal-related considerations – were formulated as 'control temperature', 'regulate temperature', 'control healthy climate' and 'cool animal'. When asked to generate animal-related solutions, the engineers came to the conclusion that the currently formulated functions did not suffice to consider animals in the solutions, and they concluded collectively that they were constrained by the words chosen. This is acknowledged in ACiD through an explicit process step in the function analysis where functions are reformulated and decomposed (3.3.3.). Function analysis and decomposition allows to shift the focus from solely technical to include biological possibilities as well. In engineering literature, there is a large body of knowledge just on the aspect of function analysis alone, that we did not cover. For example, for analysing functions of all kind of artefacts Rosenman and Gero (1998) propose a Function-Behaviour-Structure design model. This is a more sophisticated function model – by distinguishing between behaviour and structure – and could improve the contribution of ACiD to the definition of functions, than the model of Siers (2004) which uses a verb + noun structure, that we used.

During the three EWS it became apparent that ACiD helps the engineers to obtain a different mind-set. Primarily, because the engineers were forced to structurally consider the animal at different design steps and were stimulated in contemplating how the animal could contribute. Andreasen (2003) concluded that tool users often lack the necessary mind-set for the correct application of a tool. This was demonstrated in the EWS: some ACiD users were naturally hesitant and doubtful about the animal as a contributor, thereby doubting the approach's added value. In the feedback the main reason given was the (perceived) insecurity of 'giving away' control. Uncertainty underlies this strong adherence to control. Uncertainty, (1) on how to regulate a system that is partly dependent on animals and their actions, (2) on how to deal with unintended consequences: more behavioural freedom of animals leads to new interactions and conditions and therefore unforeseen emergent properties, and (3) on the display of undesired behaviour by the animal because of a higher degree of 'freedom'. In practice though, every design already has unintended consequences. Designed system elements are often used differently by the user than intended by the engineer or designer in general. The theory of affordances of Gibson defines affordances as 'an action possibility available in the environment to an individual, independent of the individual's ability to perceive this possibility' (Greeno, 1994). In other words, affordances are the (in) visible, (un)known and (un)desirable possibilities in the environment on which the user can act. In the design of livestock systems in which animals have more action possibilities, the aim is to create affordances that support desired behaviour and avoid undesired behaviours. Designers that design the structure of a system are in fact creating and changing affordances (Maier and Fadel, 2009). Affordances as a concept is not employed in the animal incorporating approach, however it is certainly a point of interest (Fig. 1).

4.2. Capacities

We use the concept of capacities to make the connection between the animal and the engineering domain. However, abstraction of the myriad of variations of what the animal could display and perform is necessary for a capacity to be used fruitfully in a design process. Also, several iterations are needed to come from biological information, to functions and eventually to solutions. Abstraction and iteration are means to cope with the complexity of incorporating the animal – represented by capacities and not as an animal being physically present – in the design process as a contributor to system functions. An engineer must keep in mind that a capacity is a complex construct that depends on an animal's individual characteristics and her external environment in the way it is expressed. Therefore, solutions based on animal capacities need further research and detailing in practice, for instance through rapid prototyping where design iterations are tested in a practical context and should always include the animal's participation, such as preference demand testing (Mancini, 2013).

In this research, an overview of an animals capacities was made to

Table 4
Function structure of the function: facilitate thermal comfort.

Sub-function	Sub(*sub*)function
Provide thermal affordances*	Provide warming affordances Provide cooling affordances
Enable access to thermal affordances	Enable access to warming affordances Enable access to cooling affordances
Operate thermal affordances	Operate warming affordances Operate cooling affordances
Use thermal affordances	Use warming affordances Use cooling affordances

* affordances refers to all the possibilities to interact with or act on an object based on users' capacities.

Table 5
Morphological chart of the function: facilitate thermal comfort.

Sub-function	Sub(*sub*)function	Technology-based solutions	Human-based solutions	Animal-based solutions
Provide thermal affordances*	Provide warming affordances	• Heater • Warm wall • Warm floor/carpet	• Provide straw	• Generate heat • Transfer heat
	Provide cooling affordances	• Air-conditioning • Shower • Mud pool • Cool floor/carpet	• Provide water/mud	• Transfer heat
Enable access to thermal affordances	Enable access to warming affordances	• Gates • Space	• Escort animals	• Walking towards warming affordance
	Enable access to cooling affordances	• Gates • Space	• Escort animals	• Walking towards cooling affordance
Operate thermal affordances	Operate warming affordances	• Automatic temperature control system	• Manually control temperature	• Manipulate temperature control system (through snout, mouth, tongue, teeth, and/or paws)
	Operate cooling affordances	• Automatic air-conditioning control system	• Manually control air-conditioning	• Manipulate air-conditioning (through snout, mouth, tongue, teeth, and/or paws)
Use thermal affordances	Use warming affordances			• Hugging warm wall • Huddling • Lying on warm floor/carpet
	Use cooling affordances			• Lying on cool floor/carpet • Wallowing in (mud) pool

* affordances refers to all the possibilities to interact with or act on an object based on users' capacities.

assist in connecting the engineering and biological domain. However, one cannot examine these capacities as parts in itself without considering the whole – the animal and its environment – with all its (un) known relations and interactions. While the BoC helps to find capacities of interest, the task of the designer remains to consult biologists, ethologists, biological literature and/or experts from the field for detailed information on the capacity. This does not mean the BoC is insignificant: the BoC assists in considering capacities – perhaps unknown to the designer – at the right step in the design process, as well as providing enough information to evaluate whether a capacity can be used as (part of) a solution for a function. Further exploration of the capacity is crucial since there is a wide range of external and internal conditions which cannot completely be accounted for in the BoC.

An important difference between the current research and the research on the capability approach of Nussbaum (2001) is that the ACiD approach aims to enlarge the possibilities to perform capacities whereas the capabilities list presented by Nussbaum (2011) is an overview of capabilities that all should be met in order to achieve human wellbeing. In a philosophical exploration of taking the capability approach to design, Oosterlaken (2013), specifically suggests not to give a fixed list of capabilities and systematic guidance in how to work with the capabilities concept in design. According to Oosterlaken the benefits are in the examples and they suggest to give as many examples as possible to open up the mind of the designer. We see the benefits of having both, providing examples, such as the dust bath unit for laying hens (van Weeghel et al., 2016) as well as an overview of capacities.

4.3. Implications for the BoC

Even though the proposed approach in this paper is explicitly motivated by improving animal welfare and integrating animal agency into design practice, there is a risk of misuse. There is no safety measure that hinders choices to use animal capacities in such a way that it might have negative welfare consequences for the animal or animals. If we would determine desirable and undesirable capacities and their impacts, which is certainly a matter of debate in itself, we would compromise the capacities overview. It is in the application of ACiD and the use of the BoC where misuse should be prevented. The formulation of additional animal welfare requirements (3.3.2.), is our proposed process step to mitigate for the potential misuse of animal capacities.

The structure of the BoC was developed based on an application for pigs. For this reason, not all animal capacities are covered, since other animal species will have unique capacities not shared with pigs. Capacities that might even force to change or extend the current structure of the BoC, for instance the introduction of additional capacity attributes to accommodate other knowledge questions. Animals with unique capacities provide interesting insights, for example flight formations of birds or symbioses between animals. Therefore, further development of the BoC structure would benefit from applying it to other animal species.

A next step is to elaborate the BoC of the pig with relevant biological content. This requires further research on the search, representation and the incorporation of biological knowledge into the structure of a BoC. Explication on how to search, find and translate biological information into the technical tool would aid in the elaboration of the BoC of the pig as well as that of other species.

5. Conclusion

In this study, the animal capacities in design (ACiD) approach was proposed as add-on to the design process of more sustainable animal production systems. With the ACiD approach, livestock husbandry engineers are provided with a Brief of Capacities (BoC) tool as well as user and application instructions to deploy biological knowledge of animals in a structured manner. The biology of an animal provides valuable information about physiology, morphology, and behaviour to be incorporated in the design of animal production systems. By using this information in the design process animals may gain more control over their environment which is an important prerequisite of good animal welfare. Currently, animals in animal production systems and their biological capacities are not fully utilized in Engineering Design (ED). ED could benefit from the animals' inherent capacities, as they provide solutions to functions in the system that do not need to be solely technically resolved. The promise is a mutual beneficial relation between human goals and good animal welfare in future livestock husbandry systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We like to thank all participants of the workshops for their important and useful contributions to this work. We are very grateful for the work of Jessica Cornelissen, who improved the use of English in the manuscript and the organisation of the text. We would also like to thank the two anonymous reviewers for their helpful feedback. This research was financially supported by the Dutch Ministry of Agriculture, Nature and Food Quality as part of project KB-12-002.04-004. Additional financial contribution was provided by Topsector Agri & Food as part of the project 'Design for a more healthy poultry husbandry' (MIP AF-16204a).

References

Andreasen, M.M., 2003. Improving design methods' usability by a mindset approach. In: Lindemann, U. (Ed.), Human Behaviour in Design: Individuals, Teams, Tools. Springer Berlin Heidelberg, co, pp. 209–218.

Bassett, L., Buchanan-Smith, H.M., 2007. Effects of predictability on the welfare of captive animals. Appl. Anim. Behav. Sci. 102, 223–245.

Bos, A.P., Groot Koerkamp, P.W.G., Groenestein, K., 2003. A novel design approach for livestock housing based on recursive control - with examples to reduce environmental pollution. Livest. Prod. Sci. 84, 157–170.

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, 137–145.

Bracke, M.B.M., Hopster, H., 2006. Assessing the importance of natural behavior for animal welfare. J. Agric. Environ. Ethics 19, 77–89.

Bracke, M.B.M., Spruijt, B.M., Metz, J.H.M., 1999. Overall animal welfare reviewed. Part 3: welfare assessment based on needs and supported by expert opinion. Neth. J. Agric. Sci. 47 (3–4), 307–322.

de Haas, E.N., Bolhuis, J.E., Kemp, B., Groothuis, T.G.G., Rodenburg, T.B., 2014. Parents and early life environment affect behavioral development of laying hen chickens. PLoS One 9, e90577de.

Desmet, P.M., Pohlmeyer, A.E., 2013. Positive design: an introduction to design for subjective well-being. Int. J. Des. 7, 5–19.

Elzen, B., Bos, B., 2019. The RIO approach: design and anchoring of sustainable animal husbandry systems. Technol. Forecast. Soc. Chang. 145, 141–152.

Greeno, J.G., 1994. Gibson's affordances. Psychol. Rev. 101, 336–342.

Groot Koerkamp, P.W.G., Bos, A.P., 2008. Designing complex and sustainable agricultural production systems: an integrated and reflexive approach for the case of table egg production in the Netherlands. NJAS Wageningen J. Life Sci. 55, 113–138.

Hall, S., Lima, M., 2001. Problem–solving approaches and philosophies in biological engineering: challenges from technical, social, and ethical arenas. Trans. ASAE 44, 1037.

Johnson, G.B., Raven, P.H., 2001. Biology: Principles & Explorations. Holt, Rinehart and Winston, Orlando, FL.

Leotti, L.A., Iyengar, S.S., Ochsner, K.N., 2010. Born to choose: the origins and value of the need for control. Trends Cogn. Sci. 14, 457–463.

Maier, J.R., Fadel, G.M., 2009. Affordance based design: a relational theory for design. Res. Eng. Des. 20, 13–27.

Mancini, C., 2013. Animal-computer interaction (ACI) changing perspective on HCI, participation and sustainability. In: CHI'13 Extended Abstracts on Human Factors in Computing Systems, pp. 2227–2236.

Manteuffel, G., Langbein, J., Puppe, B., 2009. Increasing farm animal welfare by positively motivated instrumental behaviour. Appl. Anim. Behav. Sci. 118, 191–198.

Martin, G., 2015. A conceptual framework to support adaptation of farming systems–development and application with forage rummy. Agric. Syst. 132, 52–61.

Mellor, D.J., 2012. Animal emotions, behaviour and the promotion of positive welfare states. N. Z. Vet. J. 60, 1–8.

Mellor, D.J., 2016. Updating animal welfare thinking: moving beyond the "five freedoms" towards "a Life Worth Living". Animals 6, 21.

Meynard, J.M., Dedieu, B., Bos, B., 2012. Re-design and co-design of farming systems. An overview of methods and practices. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, Dordrecht, pp. 405–429.

Mitsch, W.J., Jørgensen, S.E., 2003. Ecological engineering: a field whose time has come. Ecol. Eng. 20, 363–377.

Moraine, M., Mélac, P., Ryschawy, J., Duru, M., Therond, O., 2017. A participatory method for the design and integrated assessment of crop-livestock systems in farmers' groups. Ecol. Indic. 72, 340–351.

Nussbaum, M.C., 2001. Women and Human Development: The Capabilities Approach. Cambridge University Press.

Nussbaum, M.C., 2011. Creating Capabilities. Harvard University Press.

Oosterlaken, E.T., 2013. Taking a Capability Approach to Technology and its Design: A Philosophical Exploration. Delft University of Technology, Delft.

Pahl, G., Beitz, W., 2013. Engineering Design: A Systematic Approach. Springer Science & Business Media, London.

Puente-Rodríguez, D., Bos, A.B., 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.

Reece, J.B., Campbell, N.A., 2011. Campbell Biology. Benjamin Cummings / Pearson, Boston.

Robeyns, I., 2011. The capability approach. In: Zalta, E.N. (Ed.), The Stanford Encyclopedia of Philosophy (Summer 2011 edition).

Rodenburg, T.B., Koene, P., 2007. The impact of group size on damaging behaviours, aggression, fear and stress in farm animals. Appl. Anim. Behav. Sci. 103, 205–214.

Romera, A.J., Bos, A.P., Neal, M., Eastwood, C.R., Chapman, D., McWilliam, W., Royds, D., O'Connor, C., Brookes, R., Connolly, J., 2020. Designing future dairy systems for New Zealand using reflexive interactive design. Agric. Syst. 181, 102818.

Rosenman, M.A., Gero, J.S., 1998. Purpose and function in design: from the socio-cultural to the techno-physical. Des. Stud. 19, 161–186.

Sambrook, T.D., Buchanan-Smith, H.M., 1997. Control and complexity in novel object enrichment. Anim. Welf. 6, 207–216.

Sartori, J., Pal, U., Chakrabarti, A., 2010. A methodology for supporting "transfer" in biomimetic design. AI EDAM 24, 483–506.

Sen, A., 1999. Development as Freedom. Alfred A, Knopf, New York.

Shahare, M., 2015. Uncertainty and the capability approach to design. Curr. Sci. 109, 1665–1671.

Shettleworth, S.J., 2001. Animal cognition and animal behaviour. Anim. Behav. 61, 277–286.

Siers, F.J., 2004. Methodisch Ontwerpen Volgens H.H. van den Kroonenberg. Wolters-Noordhoff, Amsterdam.

Špinka, M., Wemelsfelder, F., 2011. Environmental challenge and animal agency. Anim. Welf. 2, 27–44.

Ursinus, W.W., Van Reenen, C.G., Reimert, I., Bolhuis, J.E., 2014. Tail biting in pigs: blood serotonin and fearfulness as pieces of the puzzle? PLoS One 9, e107040.

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.

Wageningen UR Project team "Animal Oriented Design for Pigs", 2012. What the Pig Wants: From Needs to Husbandry Designs. Wageningen UR Livestock Research, Wageningen/Lelystad, p. 36.

Wemelsfelder, F., 1997. The scientific validity of subjective concepts in models of animal welfare. Appl. Anim. Behav. Sci. 53, 75–88.

Wood-Gush, D.G., Vestergaard, K., 1989. Exploratory behavior and the welfare of intensively kept animals. J. Agric. Ethics 2, 161–169.

Yeates, J.W., 2017. How good? Ethical criteria for a 'good life' for farm animals. J. Agric. Environ. Ethics 30, 23–35.