Precision Livestock Farming: creating order beyond control

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Abstract

This paper puts precision livestock farming (PLF) in a broader perspective of agricultural engineering and its meaning for a sustainable development of animal production systems (APS). Fundamentally, it is argued that order in APS can be created in other ways than by management of livestock farming using the principles and measurement and control technology from process engineering. APS are complex and heterogeneous systems that are part of a food chain and influenced by requirements of consumers, government and civilians. Application of engineering principles to APS covers the study, understanding, management and innovation of these systems. Finally, two possible alternative strategies are presented how PLF can be interpreted and implemented in engineering practices. Firstly, the approach of recursive control as an alternative to traditional control, and secondly the Reflexive Interactive Design approach as a tool to innovate APS in their wider context.

Keywords: recursive control, engineering principles, reflexive interactive design, animal production systems

Introduction

Sustainable animal production is a big challenge in an increasingly global market, with changing national and European legislation and standards. Sustainable production or sustainable development is generally considered to deal with economically efficient, ecologically sound and socially acceptable manners. Already at the 1st European Conference on Precision Livestock Farming (PLF) expectations were set that the use of technological innovations such as sensor technology can have a meaningful effect for sustainable animal production, e.g. improved profitability, but also animal welfare and product quality. Sensor technology offers the opportunity to immediately indicate stress or the suspected presence of a livestock disease, and the ability to measure the product quality of milk and meat helps to optimize husbandry methods without any doubt. An extensive overview of the developments, possibilities and perspectives (chances and threats) of PLF are given by Wathes *et al.* (2005). They concluded with four major hurdles to be overcome: 1) technology development, 2) meaningful applications in livestock farming, 3) commercially sound perspectives, and 4) bioethical issues.
In this paper we shall put PLF in a broader perspective of agricultural engineering and its meaning for a sustainable development of animal production systems. Finally, we will come up with possible alternative strategies how PLF can be interpreted and implemented in engineering practices.

Precision Livestock Farming

The goals of PLF were initially identified as follows (1st ECPLF; Cox, 2003):

1. to improve data transfer for all agricultural production systems for plants and livestock when identifying location coordinates, partly with real time allocation,
2. to integrate relevant data generated in super-ordinate management systems,
3. to use control loops and information systems to improve consumer confidence, to improve health and comfort of humans and animals, and to conserve the environment and natural resources.

Wathes *et al.* (2005) defined PLF as the management of livestock farming using the principles and technology of process engineering, whereby PLF treats livestock production as a set of interlinked processes, which act together in a complex network. Typical examples of the PLF approach are (Cox, 2003; 2005):

- Measurement and control of parameters in the animal production process, e.g. temperature, feed intake, heart rate, weight gain, etc.
- Measurement and control of product quality parameters.
- Sensor technology in general.
- Measurement of quality parameters of inputs, e.g. feed.
- Management and control to reduce environmental effects.

As can be seen from this list, there seems to be an intrinsic connection between (better) measurements and (better) control. The precision in PLF thus amounts to increased or improved control, by means of 1) detailed knowledge about inputs, processes and variation in outcome, 2) acting specifically, and 3) applying inputs efficiently and being confident on the characteristics of the actual output. Although it might seem a completely logical connection, we want to cast doubt here on the necessity of the connection between the existence of variation in APS, increased precision and increased control. As a matter of fact the idea of being *precise* in precision agriculture (PA) and PLF refers to a more precise fulfilment of the needs of plants and animals, respectively, and thereby improving processes and reducing negative side-effects. We think that interesting and useful knowledge of variations in APS should not automatically lead to the seemingly self-evident next step of engineering or applying more technical controls. Being precise could amount as well to a reduction of man-made controls, and/or a reallocation of controlling power – for instance to animals themselves, to consumers, and to naturally occurring physical processes. Being precise might be attained by reducing instead of increasing the number of controls within our production systems. The basic question that plays a central role is 'How is order in animal productions systems realised?'

A systems approach

To come to a more precise look at PLF let us apply a systems approach to animal production systems. Animal production systems can be described as *complex, heterogeneous (technological) systems* (Bos, 2004; Wathes *et al.*, 2005). This means that:

1. The major entities in a simplified model of reality are the production animals, the human being that provides labour and manages processes, and 'technique'. Technique can be 'defined' as anything (generally hardware and software) in the production system that is put there by man, and thus making the difference with nature or natural production systems.
2. Complexity results from the many and often non-linear relations between the entities within (and outside) the system boundaries.
3. Heterogeneity is caused by the essential differences between the types of entities (living, non-living, human, non-human), but also within entities (e.g. variation between animals).
4. A system has a boundary, implying that there is also an outer world (or environment) that doesn't belong to it, and it materially exists for a given period of time.

The above list is a specification for the case of biological production systems of the system description by Radder (2007): 'A system [can be defined as] any aggregate (or collective) of mutually interacting material entities within a certain region of space and time. (…) By definition,

everything that is not included in the system is its environment. The relevant part of the environment comprises the conditions for the successful working of the technology in question.'
Production systems are part of a chain with input and output relations, but also are influenced by legislation from governmental bodies and societal concerns as often expressed by non-governmental organizations. This results in the schematic model as given in Figure 1 of animal production systems in a wider context. Consumers of food desire safety food production, a high quality product and acceptable prices. Requirements on sustainable production methods at the primary animal production system, e.g. animal welfare, are sometimes embedded in the food chain, but traditionally most of the times put forward by laws and regulations, and nowadays even more often by societal organisations. In many cases the requirements regarding sustainable production are clear, measurable and goal related, e.g. emissions to the environment, but can also be unclear, emotional and not uniquely measurable, e.g. welfare of animals.

Agricultural engineering

Having this model of animal production systems and their wider context, it is time to have a closer look at the basics of agricultural engineering. What is agricultural engineering and how can it contribute to sustainable production? The American Society of Agricultural and Biological Engineers gives the following description of 'agricultural engineering': 'Biological and Agricultural engineering is the application of engineering principles to any process associated with producing agriculturally based goods and management of our natural resources. We do this with a constant eye toward improved protection of people, animals and the environment.' We like to further develop and elaborate on the 'engineering principles' when biological production systems are considered, and propose the following engineering fields:
1. to study;
2. to understand;
3. to manage, and
4. to innovate complex heterogeneous biological production systems.

In Figure 2 basic schematic models are presented for these four fields, whereby innovations of systems is split up in innovation of process (d) and innovation of complete systems (e).

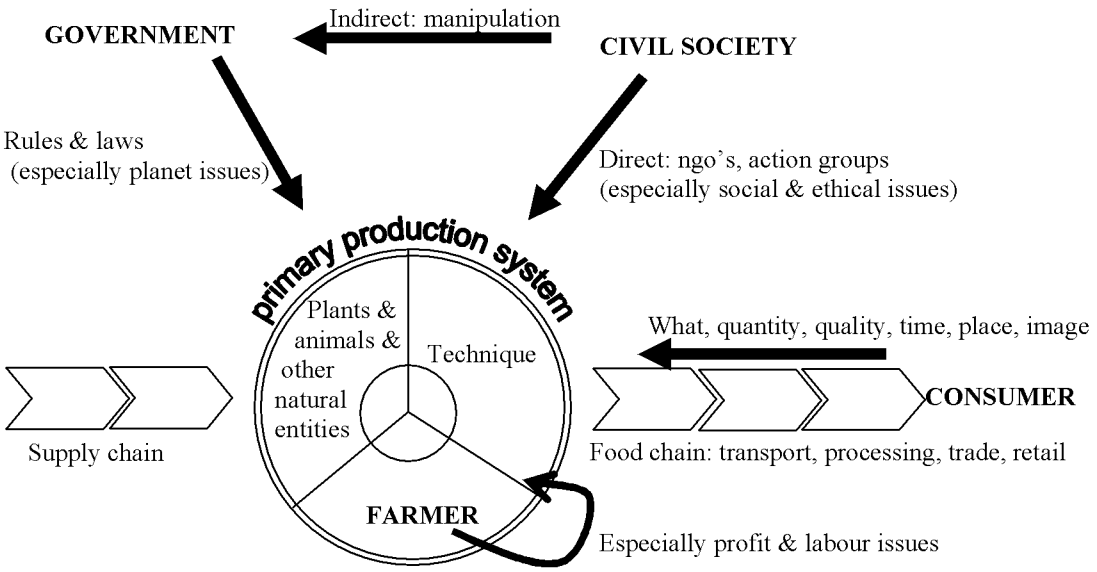

Figure 1. Schematic model of an animal production system as part of a chain and the outer world. The four major actors are given in bold.

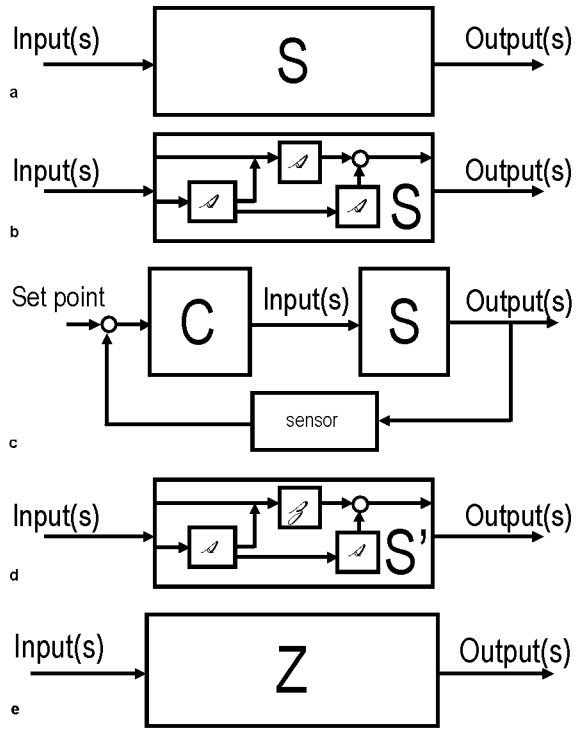

Figure 2. Five schematic representations of agricultural engineering fields of animal production system: a) study the relation between input and output of system S; b) understand and ultimately model the working of system S with processes s; c) manage or control the output of system S by means of feedback controller C; d) innovate or improve a single process from s to z; e) innovate the complete system S to Z. d) and e) can also be implemented in control loops as in c).

The study of input – output relations of existing animal production systems (APS) represented by S is often the start of a new application of agricultural engineering. Alternatively, different existing systems are compared with each other based on their output. Research into the ammonia emission (output) of two types of housing systems for laying hens, battery cage versus aviary system, and the dependence on the removal frequency of the manure on the belts (Groot Koerkamp, 1998) is a typical example. The output of a system is not necessarily physical output but can also be a process parameter within the system, e.g. mortality of animals. Besides the focus on the input-output relations the engineering focus in this field is often also on the development of new adequate sensors to measure the output, to measure more accurate, continuously or automatically.

The understanding of a system is often the next step in research of biological production systems. The system is split up in subsystems, often representing separate processes, and relations between them are identified, qualified and quantified. The ultimate way of understanding complex system is to build a computer model of them, and validate the model with data from an existing system. An interesting example of this is the behaviour model of cows in cubicle houses (Halachmi, 1999).

The next step in engineering of APS focuses on the alleviation or solution of the actual problem that is encountered with the output of the current system. The focus is then on the development of adequate controllers to manipulate the input, with the help of various types of model based feed back systems. Typical examples are the control of the indoor temperature in animal houses (Wagenberg *et al.*, 2005), or control of the weight gain of broilers by means of feed supply (Berckmans *et al.*, 2003).

Innovation or change of APS is often necessary to fulfil the sustainability requirements on the output of a system S. This is because sustainability requirements are in most cases multiple and diverse. Improving solely on one dimension would likely have an undesired negative effect on the performance of other sustainability criteria. In the first step (sub-) processes of the system are

altered. Essentially, existing functions are fulfilled in another way or, using additional techniques, new functions are added to the system. Functions in complex systems and the way they are fulfilled are the key in the 'structured design approach' of Kroonenberg (Siers, 2004) to innovate systems. Reduction of ammonia emission from pig houses can be achieved by minimising the emitting area and volume of slurry under the slatted floor. The functions 'collection' and 'storage' of slurry are changed in this case, being crucial to the ammonia emission process, but they are only sub-functions in the system with function 'house pigs'. Typical for process innovation is the implementation of new parts of techniques, as in the example. Automation, mechanization and ultimately robotization are typically new ways to fulfil functions of the system.
If more or even many processes are changed within a system we can identify a system innovation; a new system is born. In some cases such system innovations start at the drawing table of designers (DTO; Weaver *et al.*, 2000) and engineers (Hercules project; Ogink *et al.*, 2000), but often it is a gradual change that starts with the change of one process, that finally affects many others. An interesting example of this is the development and implementation of the automatic milking system (AMS). Basically the AMS is an alternative solution to the current milking systems to fulfil the function 'remove milk from cow'. As such, it is a process innovation. However, unreflective orientation on one aspect of a technological system can result in unforeseen or un-assessed side effects. During the past decade the whole husbandry system for cows was adapted to this new milking technique and gradually other technical changes were introduced. For example selection on the milking behaviour and udder uniformity of cows, a new layout of cubicle houses, and less grazing in pastures.

Sustainable development and position of PLF

In the theory of sustainable development, three types of innovation and their effect on output parameters of systems are identified, and schematically drawn in Figure 3. This figure typically shows that optimization and process innovation have best effects on the short run, but these effects are limited and fade out on the longer run. For substantial improvement system innovation is needed, based on fulfilling the needs of actors and new ways how functions are fulfilled. Optimization is characterized by the improvement of current processes and systems and typically leads to *better techniques*, whereas process innovation can be characterized by (partly) replacement of techniques and typically leads to the *introduction of new techniques*. System innovation is characterized by a structural rearrangement of the system components: more often than not, this means that not only the technique changes, but also the entrenched social structures and associated cultural beliefs. The

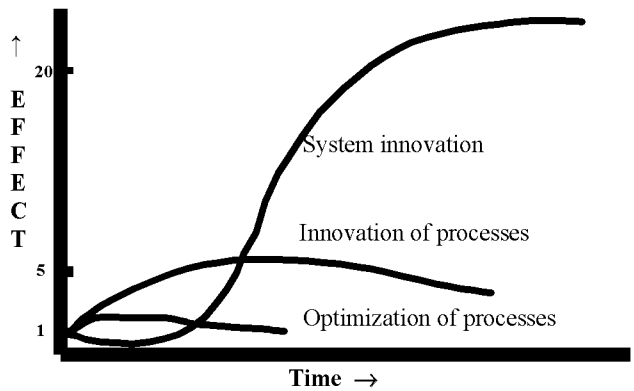

Figure 3. Three types of innovation of processes and systems and their effect on output of systems (after Weaver *et al.*, 2000).

theory of reflexive modernization (Beck *et al.*, 1994; Beck, 1997) reminds us of the importance of assessing the possible effects of changes on all these dimensions beforehand, in order to prevent a repetition of - what they call - first modernity, that due to an exclusive focus on one dimension (for instance speed, or cost) is increasingly confronted with risks and negative side effects that result from modernization itself. Typical examples of system innovation is the development of slurry systems for cows (from tie houses to cubicle houses). It was not only a revolution for the husbandry system, but also enabled further growth of farms and increased labour efficiency, and had major effect on landscape and rural developments.

So far, PLF has typically concentrated on the third engineering theme in figure 2 'the management and control of animal production systems', with the help of theme 1 (study input – output relations and sensor development) and theme 2 (modelling). It is thus shaped largely as an optimization tool of current systems, leaving their structural arrangements intact, but adding more precise measurements, and (anticipating on) a growing number of control features in the system (by developing sensor techniques).

Therefore, the answer to the question 'What could be the contribution of PLF on sustainable development of animal production systems?' is not yet known. More strongly stated, current PLF is a collection of attempts to optimize the systems of today on specific one dimensional aspects, without reflecting on their possible structural limitations of failures. In that sense PLF might run the risk of repeating the mistakes of our grand and glorious history of modernization in livestock production: optimizing on the one hand, but adding a range of undesired side effects on the other. Therefore, it is important to reflect a while on some of the basic, and often hidden or unarticulated assumptions and restrictions in the current interpretations of PLF. A first list of these reflections is given below:

- Precision is always good.
- PLF equals precision with control. This is problematic for several reasons. First, control is one of the options following the need for increased precision given the variation in APS; second, this presupposes that a lack of control is the problem; third, order (which might be the desired result of control) can be attained in more ways than (technical) control (see below); fourth, more control in complex systems may well have uncontrollable effects and produce unforeseen risks (Perrow, 1984).
- The presupposed controller is either a human being (e.g. the farmer) or a machine entity (e.g. a robot or PLC- programmable logic controller), but never a plant, a virus, an insect or an animal. Biological pest reduction is an example of a very precise natural form of control without human made sensors, and without human-made controls.
- Precision might enable differentiation towards individual living entities, but may as well, as a side-effect, support the tendency for homogenization and standardization. AMS's give milking freedom to cows, but meanwhile induce a strong tendency to select cows on AMS-able udders.
- Current systems have their limits and we have to consider to what extent better management and control can improve things and ultimately fulfil ecological, economical and social requirements.
- Measurement and control by man and technology is the only way to solve a problem or achieve the sustainability goals.
- New technology can solve the problems, even if we approach the problems in a multi-disciplinary way.
- No other changes within or outside the system are needed, while one can expect that structures, cultural believes and power relations may hamper introduction of new technology or may even be counterproductive.
- What is the history and societal idea of current systems? Can societal acceptance be reduced to a single welfare parameter that is controlled by PLF, or environmental impact by the control of ammonia emission only?

What we want to show by highlighting these assumptions is that the promise of PLF that it can contribute to sustainable development might turn out to be false, as long as it sticks to control of current systems. As long as PLF does not fundamentally address its role in the structural arrangements of current and future APS, PLF might only be the servant of livestock production systems to survive for a while, by just optimizing and innovating on specific processes within these systems. We believe this is not enough for real sustainable development, and – more seriously – this contribution of PLF might actually hinder developments that do matter.

Making the next step

PLF as an engineering approach might have a great potential in sustainable development if it starts doing at least the following things:

1. Associate itself with restructuring of complex heterogeneous systems.
2. Reflect on what it means to be 'precise' and what the possible consequences and opportunities of action might be.
3. Avoid the reflex of adding a control to a single piece of 'precise' information.
4. Reflect on the target of precise information (it might be an animal as well!).
5. Who's the sensor? Who's the controller?
6. Could PLF contribute to less controls instead of more?

To make this more tangible, we shortly propose two new ways to think about the development of technology that contributes to sustainable APS:

1. On the engineering side: recursive control by living organisms as an alternate means to create order in complex biological systems.
2. On the management/process side: reflexive interactive design (RID) as an approach to systematically think, design and act towards system innovations.

Ad 1. Recursive control by the animal and nature

Traditional approaches in animal husbandry, and also the approaches to solve problems, are often and primarily based on unidirectional technical solutions, in which control is exclusively exerted over both dead matter and living entities. In Bos *et al.* (2003) a novel approach is presented to combine the nature of animals with the prevention and reduction of environmental pollution based on recursive control. This approach is based on the presence, knowledge and use of the natural behaviour of animals and their interrelation in the population. It is claimed that order in complex systems like these can be the result of animal interactions with their environment as well, without detailed human and technical intervention and surveillance. A fundamental precondition for this is a considerable degree of slack, or play, in order to give animals the latitude to adapt to changing local circumstances in the animal house. Two examples are given that support the theory: first the control of ammonia emission from a straw-based group housing system for sows, and second the collection of as much faeces possible from the hens in an aviary housing system for laying hens. Fundamental to this approach is that we have to consider that an animal not only responds to changes in its environment, but that the animal also influences the environment for its own purposes, see Figure 4.

Ad 2. System innovation through Reflexive Interactive Design (RID)

The basic idea of system innovations is a structural reorientation of a system. If sustainability is at stake, most probably a multiplicity of problems should be dealt with at once. To make it even more complicated, these problems are often subject to values and political beliefs that are inherently contested. In these instances, the work of an engineer does not take place on neutral ground. Moreover, from the philosophy of technology and science & technology studies we know that engineers play a role in materially realizing politics and values into technical artefacts. Values

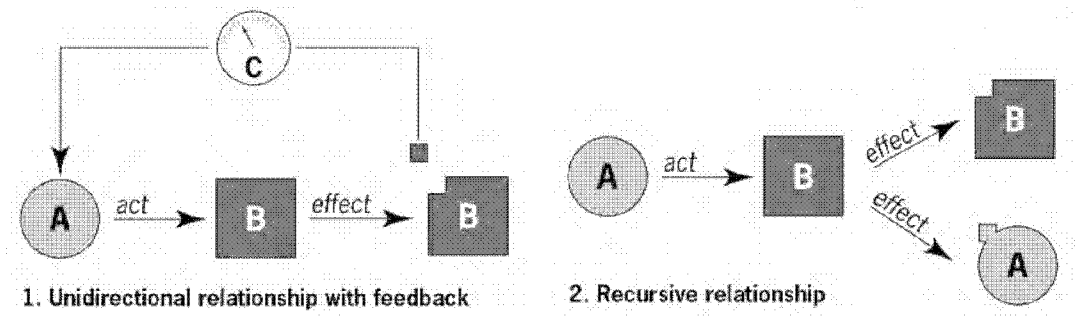

Figure 4. Graphical representation of a unidirectional (1) and a recursive relationship (2). In a unidirectional relationship, the act of A can only be influenced by its effect if the effect is deliberately fed back via a third process or actor C. In a recursive relationship, the act of A intrinsically has an effect on A itself, besides the effect on B. No third process or actor is needed. In both cases, order results, but under conceptually different conditions (Bos *et al.*, 2003).

are 'cast in stone' as it were. This might be done deliberately, but more often than not, this is done implicitly and unreflectively.

From our experience in engineering APS for sustainability, we derived an approach that aims to combine a systematic engineering approach (based on the structured design approach; Siers, 2004) with an interactive and reflexive approach towards integrating values and politics into new systems that comply with ambitious sustainability criteria –set by stakeholders and the wider environment. We call this approach Reflexive Interactive Design (RID). It is reflexive in the sense that it systematically addresses the presuppositions of current systems and current institutions, but also addresses the assumptions that lay the foundation for our own work. This isn't only abstract philosophy: it amounts to very concrete questions like what is the problem actually, whose needs are at stake actually, what is the supposed function of the system and what is to be produced, and what is the general cognitive framework we ourselves work with. It is reflexive also, in the sense that stakeholders will be challenged to dig deeper into their conception of the world and their perceived and desired identity in the future, and to reflect on what is really at stake for them.

RID is fundamentally interactive, because we believe that any design process will lead to concepts or artefacts that are a specific expression of values and political orientation. An exclusive engineering approach would neglect this. A next reason for interactivity is the use of knowledge of very diverse origin.

RID starts with a fundamental assessment of the structural arrangements that constrain and enable the current production system under study. An interactively set agenda of strategic challenges (on the structural level) will orient the subsequent design phase, which starts with an elaborate analysis of the needs of the living entities involved in the system (for instance, the farmer and the production animal, but also think about the other living entities that might be useful or harmful to your goals).

The RID approach ultimately aims to prevent the repetition of entrenched patterns of thought and design, that shaped the first phase of modernization of APS. Firstly, by increasing the level of reflexivity in the innovation process itself, and by stimulating mutual learning through interactivity, both the problem and solution space (Voß & Kemp, 2006) are extended. Secondly, by applying a systematic and methodical design approach (Siers, 2004) it is possible to synthesize apparently contradicting needs of a range of different actors – including the animal. By doing this, the multiplicity of sustainability challenges is dealt with in an integral way, instead of taking them as separate technical problems to be addressed one by one – thus preventing ending up with a trade off between them.

A first example of this approach is reported by Wageningen UR Projectteam Houden van Hennen (2004) and Bos (2007). Although this project delivered appealing new concepts for laying hen husbandry as well, the more enduring results of it are the new connections made between institutional actors within the current system, and the introduction of new ways of thinking on designing systems around the needs of animals as well as along the images and values of specific consumer groups. PLF does fit in in this approach in three ways: 1) it may serve as an analytical instrument to reflect on the control paradigms that reign current systems; 2) it may present a general starting point for creating order in new systems to be designed, provided it untangles its current tight connection between precision and a specific type of control; and 3) it may provide us with a range of specific solutions for specific demands, defined during the design process.

References

Beck, U., A. Giddens and S. Lash. 1994. Reflexive modernization. Cambridge: Polity Press.

Beck, U., 1997. The reinvention of politics. Rethinking Modernity in the Global Social Order. Polity Press, Cambridge.

Berckmans, D., J.M. Aerts and S. van Buggenhout, 2003. Controlling growth of broiler chickens on-line, based on a compact predictive growth model. Proceedings 1st European Congress on Precision Livestock Farming (Ed. S. Cox), Wageningen Academic Publishers, Wageningen, p. 27-32.

Bos, B., P.W.G. Groot Koerkamp and C.M. Groenestein, 2003. A novel design approach for livestock housing based on recursive control – with examples to reduce environmental pollution. Livestock Production Science 84 (2003): 157–170.

Bos, B., 2004. Een kwestie van beheersing – over de rol van planten, dieren en mensen in technologische systemen (A matter of control – about the role of plants, animals and human in technological systems). PhD thesis Vrije Universiteit Amsterdam, De vliegende beer, Amsterdam, 192 p.

Bos, B., 2007. Instrumentalization Theory and Reflexive Design in Animal Husbandry. Accepted for publication in Social Epistemology.

Cox, S., 2003 (Ed.). Proceedings of the 1st European Congress on Precision Livestock Farming, Wageningen Academic Publishers, Wageningen, 183 p.

Cox, S., 2005 (Ed.). Proceedings of the 2nd European Congress on Precision Livestock Farming, Wageningen Academic Publishers, Wageningen, 358 p.

Groot Koerkamp, P.W.G., 1998. Ammonia emission form aviary housing systems for laying hens – inventory, characteristics and solutions. PhD thesis, Wageningen University, Wageningen, 161 p.

Halachmi, I., 1999. Design methodology for the robotic milking barn – modelling, simulation, validation and optimization. PhD thesis, Wageningen Unversity, Wageningen, 140 p.

Ogink, N.W.M.., H.C. Willers, ,A.H.M. Veeken and H.V.M. Hamelers, 2000. The Hercules pig production system: a new farm system for sustainable production of pigs and fertilisers. proceedings of the AgEng Conference, June 2000, Warwick, UK.

Perrow, C. 1984. Normal Accidents – living with high-risk technologies. Basic Books, New York.

Radder, H., 2007. Critical Philosophy of Technology: The Basic Issues. Accepted for publication in Social Epistemology.

Siers, F.J., 2004. Methodisch Ontwerpen volgens H.H. Kroonenberg (Structured Design according Kroonenberg). Wolters-Noordhoff, Amsterdam, 223 pp. (in Dutch).

Voß, J.P. and R. Kemp, 2006. Sustainability and reflexive governance: Introduction. In J.P. Voß, D. Bauknecht and R. Kemp (Eds.), Reflexive governance for sustainable development. Cheltenham: Edward Elgar.

Wagenberg, A.V. van, J.M. Aerts, A. van Brecht, E. Vranken, T. Leroy and D. Berckmans, 2005. Climate control based on temperature measurement in the animal-occupied zone of a pig room with ground channel ventilation. Transactions of the ASAE 48(1): 355-365

Wageningen UR project team Houden van Hennen, 2004. Laying Hen Husbandry – towards a happy hen life, proud farmers and a satisfied society, Wageningen – Lelystad: Wageningen UR

Wathes, C.M., H.H. Kristensen, J.M. Aerts and D. Berckmans, 2005. Is precision livestock farming an engineer's daydream or nightmare, an animal's friends of foe, and a farmer's panacea or pitfall? Proceedings 2nd European Congress on Precision Livestock Farming (Ed. S. Cox), Wageningen Academic Publishers, Wageningen, p. 33-46

Weaver, P., L. Jansen, G. Van Grootveld, E. Van Spiegel and P. Vergragt, 2000. Sustainable Technology Development. Greenleaf, Sheffield.