Designing complex and sustainable agricultural production systems: an integrated and reflexive approach for the case of table egg production in the Netherlands

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Abstract

The poultry sector in the Netherlands is confronted with the EU ban on conventional cages, the public debate on the welfare of hens in furnished cages, the limited perspectives of currently used more welfare-friendly single- or multi-tiered systems (either indoor or outdoor), and with questions about the natural behaviour of animals and the robustness of current production systems. To arrive at new and sustainable husbandry systems for laying hens a new design approach was developed and applied. The work-scheme of the approach consisted of four phases: (1) collecting information and network building, (2) a thorough analysis of problems followed by making strategic choices, (3) developing a structured design, and (4) reporting and communication. The approach incorporated interdisciplinary and multi-stakeholder interactive methods, integrating scientific and tacit knowledge. The main results of the study were (1) a Brief of Requirements for the laying hen, the farmer and the citizen/consumer as key players in a sustainable development, and (2) two new attractive and feasible husbandry concepts for future egg production. The approach succeeded in identifying the underlying needs and requirements of actors, bridging the gap between seemingly conflicting requirements and stimulating new initiatives towards sustainable development.

Additional keywords: laying hens, naturalness, new husbandry concepts, reflexive interactive design (RIO), societal concern, structured design method, robustness

Introduction

Total table egg production in the European Union (EU-15) in 2002 was 93 billion, which is 3% more than its needs in that year (Anon., 2004). Total table egg production in the Netherlands in that year was 9.5 billion, of which 32% was sold domestically. The Dutch table eggs were being produced in three production systems: conventional cages (66%), multi-tiered aviary systems (7%) and single-tiered floor or barn systems (27%) (Tacken *et al.*, 2003). The last two are sometimes combined with an outdoor run, and then referred to as 'free-range systems'. The dynamics in the distribution of hens over the various housing systems since 2000 are shown in Figure 1. The EU market distinguishes four categories of table eggs: category 0 (organic – in principle with outdoor access), category 1 (free range – always with outdoor access), category 2 (multi-tiered and single-tiered floor systems – indoor), and category 3 (cages, conventional or furnished cages) (EEC regulation 1907/90).

A number of societal issues are associated with the production of table eggs in the Netherlands and the EU-15 as a whole: (1) an intense public debate about the poor welfare of caged hens that amongst other things resulted in an EU ban on conventional cages as of 2012 (EU Directive 1999/74), (2) the lack of public and political acceptance of the more welfare friendly furnished cages (e.g., Windhorst, 2006), and more specifically, (3) the risk of an outbreak of Avian Influenza, its effects on human health and the subsequent culling of millions of birds (Koch & Elbers, 2006). A transition of the egg production sector towards more sustainable production systems (Mollenhorst, 2005) that are environmentally friendly, economically feasible and socially acceptable is necessary (Binnekamp & Ingenbleek, 2006; Balkenende *et al.*, 2007).

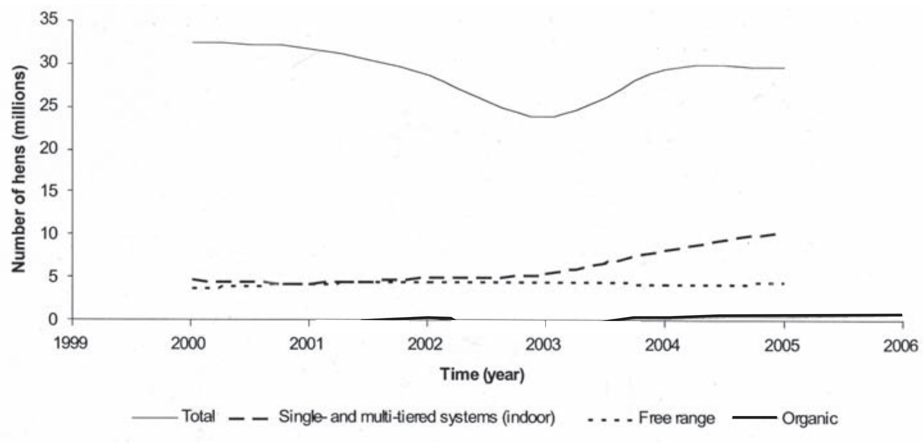

Figure 1. Changes in the number of hens per type of husbandry system in the Netherlands since 2000. In the year 2003 an outbreak of Avian Influenza occurred. Free range and organic systems generally have an outdoor access for the hens (Loefs & Methorst, 2006; Anon., 2007b).

During the period 2003–2005, the distribution of hens in various production systems in the Netherlands has changed and more hens are now housed in a more animal friendly way (Figure 1). It is nevertheless expected that the currently used non-cage systems are not a viable alternative to the battery cages on the larger farms that still house some 40% of the Dutch laying hens. The single- and multi-tiered production systems, with or without an outdoor run, have their own specific problems and negative side-effects for laying hens as well as for farmers, consumers and society. An EU inventory revealed that typical health problems in non-cage systems are particularly related to the outdoor run. These problems include (1) parasites (e.g., worms) and Avian Influenza (Meuwissen *et al.*, 2006), (2) higher production costs (labour, housing, feed; Vermeij & Horne, 2006; Vermeij, 2007), (3) food safety risks (*Salmonella*, *Campylobacter* and dioxins; De Vries *et al.*, 2006) and (4) environmental issues (higher emissions of ammonia, stench, nitrate leaching to the groundwater; Aarnink *et al.*, 2006). However, good use of an outdoor run by hens reduces the risks of feather pecking and cannibalism, and thus improves animal welfare (De Mol *et al.*, 2006; Hegelund *et al.*, 2006; Knierim, 2006). The foreseen ban in the Netherlands on beak trimming practices (Anon., 1996) strongly increases the risks of feather pecking and cannibalism in current husbandry systems, with a major impact on animal welfare and possibly increased public concern. Furthermore, there is disagreement about the evaluation of furnished cages, scientifically as well as publicly and politically, which hampers the successful introduction of these systems.

In 2003, research was started with the aim to initiate and stimulate a sustainable development of the laying hen industry in the Netherlands. Three elements were crucial. First of all, the approach of the project had to express the new role of the Dutch government in the development of a sustainable agriculture. Sustainability was to be achieved not by means of new national legislation (retreat of government), but through agreements and support of self-responsible actors that take initiative and responsibility themselves to regain their licence-to-produce, possibly in co-operation with other non-governmental organizations (so-called governance; Rhodes, 1997). Secondly, the project also had to reflect on and use the latest insights into the way of how innovations in agriculture take place and how a balance can be found between long-term attractive or idealistic views (Sustainable Technology Development – STD, Weaver *et al.*, 2000) and short-term involvement and action of farmers and other parties involved (Interactive Technology Assessment – ITA, Grin *et al.*, 1997; Strategic Niche Management – SNM, Hoogma *et al.*, 2002). Thirdly, the meaning of the terms *robustness* and *naturalness* used in the political and public debate about livestock farming had to be interpreted.

An integrated design approach was developed to design new husbandry systems for laying hens, and that at the same time could help to assess two basic questions: (1) What is a sustainable state or development of a complex food production system like the laying hen industry in the Netherlands, and from whose perspective, and (2) How can such a development be successfully initiated during the project and be stimulated afterwards? This paper describes this integrated approach for the design of complex and sustainable production systems that are part of a food chain, and its application for table egg production in the Netherlands.

Methodology

The integrated design approach

The integrated design approach consisted of five elements. First, a systems approach was chosen for analysis of the problem. Not only the ethological needs of the laying hen were taken into account, but also the needs (related to behavioural and physiological responses to maintain a preferred emotional state of living entities; needs have to be fulfilled to prevent deprivation and negative effects on welfare and health), requirements (a precise and quantifiable condition to be met in the ideal situation) and wishes (a condition preferably to be met). Perceptions, opinions and beliefs of the actors in the production system (e.g., farmers and workers) and food chain (e.g., processing and retail companies and consumers) and the relevant actors related to this food chain (citizens and consumers concerned about laying hens in husbandry systems; Verhoog, 1997) were analysed more deeply and translated into needs and requirements. Secondly, a systematic and structured design process was used for finding solutions. The method stresses a thorough analysis and definition of the problem, including identification of the needs and requirements of the relevant actors, including a functions analysis. Essentially, solutions and their related normative choices were deferred to later stages of the project. Thirdly, the project was interdisciplinary, encompassing and combining different disciplines such as animal welfare, farm management, philosophy, architecture and communication. Fourthly, both scientific and experiential (tacit) knowledge from these disciplines was used in the project. The fifth element was the close interaction with the egg production sector and

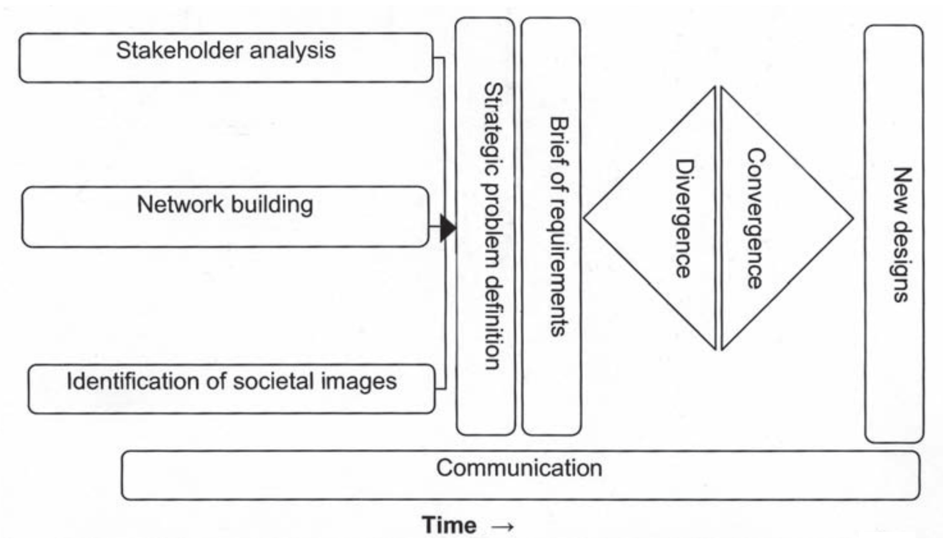

Figure 2. Work scheme of the project (partly iteratively looped – not shown). Triangles and horizontal blocks represent activities, vertical blocks represent output.

related societal groups. For the overall method a work-scheme was drawn up (Figure 2, partly iteratively looped) that incorporated the five aforementioned elements. The scheme distinguishes four more or less chronological phases: (1) collecting information and network building, (2) a thorough analysis of the problems and strategic choices, (3) steps in the design process, and (4) reporting and communication.

Below, this design method is worked out with respect to (1) the stakeholder and problem analysis and strategic choices, (2) the needs and requirements of citizens, poultry farmers and laying hens, (3) the structured design process, and (4) the terms *robustness* and *naturalness*.

Stakeholder and problem analysis and strategic choices

An in-depth study of the problem was made, initially by the project team through a literature study and personal experience, and subsequently by interaction with the relevant parties involved. The aim of this study was not only to draw up a problem analysis, but also to come forward with a so-called 'strategic problem definition'. Such a definition addresses both the essential problems and the broadly desired goals for the longer term, and was meant to formulate a long-term design objective and to define the short-term common agenda of the project and its stakeholders. Twenty persons were interviewed in person or by telephone. They included poultry farmers, people from the supply industry (like feed companies and housing-system builders), service providers (e.g., veterinarians, advisors), egg trading companies, and non-governmental organizations (NGO) amongst other ones the animal protection organizations Dierenbescherming and Wakker Dier. During the interviews a draft version of the strategic problem definition that was sent in advance to the interviewees was discussed in order to identify the priorities the interviewee would give to the project. As far as possible, it was tried to identify the origin of their preferences and dislikes. Following an analysis of the interviews the strategic problem definition was reformulated.

Needs and requirements of citizens, farmers and laying hens

The formulation of the Brief of Requirements (BoR; list of all requirements specified in quantitative terms with traceable sources, either numerically fixed or a variable range) is an important step in the structured design process (step 5; Table 2). Initially the team formulated the structure, items and requirements in accordance with the problem definition. A draft BoR for the consumer/citizen, poultry farmer and laying hen was presented for open discussion during a workshop, which resulted in a number of needs and requirements being altered or specified. For the workshop about 40 participants were selected from a database of people that had expressed their interest in the project by sending in a response form. These participants were all professionally involved or connected with poultry production. Additionally to this workshop the following specific actions were carried out; results were used as input for the final BoR.

Citizens

During the sessions, which lasted a whole day, three groups of citizens articulated their ideals concerning the keeping of laying hens. The three groups, each consisting of 6–8 citizens randomly selected from a database, were differentiated according to an established consumer model called *Mentality* (Lampert *et al.*, 2002; Anon., 2007a) that is used in marketing and political research. *Mentality* distinguishes between consumer groups on the basis of value and belief systems, rather than just socio-economic position (income, status). Value and belief systems tend to be very robust during the life of individual people, and have a rather good predictive value for consumer behaviour as well as political and ethical orientation. This makes *Mentality* a very suitable model for our purposes since it integrates the role of people as consumer and citizen, based on a robust differentiation. The individuals for the session were selected from the groups *Cosmopolitans*, *Traditional Bourgeois* and *Post-materialists*, whereas *Mentality* also distinguishes *New Conservatives*, *Modern Bourgeois*, *Social Climbers*, *Post-modern Hedonists* and *Convenience oriented*.

Sessions were organized according to a pre-defined script that included a number of separate creative techniques (see Table 1). The sessions started with a brief introduction of the central topic (ideal housing of laying hens) followed by techniques that delve deeper into the rational and emotional components of participants' views on the topic. This resulted in text, paintings, associations and drawings. These visions (drawings), as well as previously expressed ideas about chickens and farming, were transformed into numerous illustrations, initially drawn by the participants themselves, later further elaborated by professional illustrators. Full sessions were scripted verbatim and resulted in a number of different clues and images of values and ideals, both verbally and visually, which were analysed afterwards to identify general trends.

Consumers

The wishes and requirements of consumers in relation to the consumption of eggs were divided into three themes: (1) quality (taste, colour, smell, eggshell and cleanliness), (2) food safety (e.g., absence of dioxins, *Salmonella* or residues of medicines), and (3) marketing aspects (e.g., price, availability and packaging). Information from literature was checked and completed with information from two people working in egg trading and marketing of eggs.

Poultry farmers

To identify the needs and requirements of farmers, interviews were organized with 10 farmers themselves as well as their professional environment (veterinarians, system

Table 1. Techniques used and results of the sessions for three types of citizens to identify their values and beliefs on ideal housing of laying hens.

Technique	Result
Identification of synonyms and antonyms of keywords	Rational components of participants views
Visualization of techniques	Abstract paintings
Odour sensing	Emotional associations with the topic
Guided fantasy	Concrete vision of ideal keeping of laying hens

builders, banks, feed producers, etc. – 12 in all). The selection comprised farmers of all current housing systems (organic, free-range, indoor floor systems and cages).

Laying hens

The needs of laying hens were investigated using an extensive body of ethological literature (involving over 1000 scientific statements) as well as practical knowledge from farmers and other specialists. In this brief the desired level of welfare of the laying hen was defined according the fulfilment of the 'ethological needs', i.e., the needs that have to be fulfilled in order to prevent unwanted, abnormal behaviour (e.g., feather pecking & stereotypical behaviour), chronic stress and laying floor eggs (Duncan, 1998). In literature, ethological needs are being unravelled by means of behavioural studies, preference tests and operant methods (Jensen & Toates, 1993; Cooper & Albentosa, 2003). Analysis of the space requirements of laying hens per type of behaviour and activity was based on the model of De Mol *et al.* (2005). The results of Mishra *et al.* (2005) were used to identify the movement of hens between the various functional places and to quantify synchronizing behaviour.

Structured design process

The structured design process (Van Den Kroonenberg & Siers, 1999; Siers, 2004) originates from engineering design and architecture. It emphasizes a thorough investigation and analysis of the problem in relation to the needs and requirements of the prospected actors in the system (see Anon., 2003) for a previous example in animal husbandry). The detailed consecutive steps of this method are listed in Table 2. In

Table 2. Sequence of steps and results in structured design. The chronological order is combined with going back and forth between steps (iteration) (Van Den Kroonenberg & Siers, 1999).

Preliminary research	
Step 1	Analysis of the needs of the actors in the system
Step 2	Analyse both the system and its environment and identify the key elements and actors
Step 3	Identify the undesirables and set the design objective
Problem definition	
Step 4	Analysis of the problem
Step 5	Describe and list the qualitative and quantitative aspects of the needs (Brief of Requirements)
Step 6	Describe the key functions
Formulating solutions and concepts	
Step 7	Find many solutions for the key functions through scientific and tacit knowledge and creativity
Step 8	Combine solutions into structures and design concepts or drafts
Step 9	Evaluate the structures against the Brief of Requirements
Detailed design and shaping	

our case we chose as the main actors the triad laying hen, poultry farmer and citizen/consumer. A considerable part of the approach (80%) is dedicated to the preliminary research and problem definition (steps 1–6). This large share is due to the requirement in the methodology to formulate the needs as abstractly as possible without loosing its content. The identification and analysis of needs and requirements of the three groups of actors formed the basis for the BoR (step 5). Based on the strategic problem definition and BoR, key functions (trivial and new) were identified that could link the broad range of requirements with system functions for egg production, and establish synergy and compatibility at the same time. Functions describe in an abstract way the things that have to be done (the so-called 'what') to make the system run, but do not describe the way how the task is carried out. Although the structured and systematic character might suggest otherwise, structured design does allow for creativity and innovation that are given a specific place in the process (step 7 in Table 2). Solutions for the key functions were generated and listed schematically in the so-called morphologic chart. In addition, three special creativity workshops were organized to find more and new solutions for three specific problems related to key functions: (1) floor-eggs – provide laying facility, (2) the use of space ('overview' by farmer, 'not crowded' by citizens, 'sufficient for ethological needs' by the hen) – arrange and manage functional areas, and (3) animal health in relation to outdoor access – keep hens healthy. Stakeholders and case specialists as well as nonprofessional people (outsiders) participated in these workshops, where sketches were made too and all output was put on paper. The next step (step 8 in Table 2) was to select specific solutions and combine them into structures and concepts that could be part of the new total designs. Solutions were selected based on the extent to which they fulfilled or could fulfil more requirements, even in the case of requirements that seemed to contradict each other at first sight. Three discriminating sets of solutions were identified and two sets were further elaborated in the design process. The draft concepts of the designs were evaluated (step 9) by the project team and in three group meetings with five people through scoring against the Brief of Requirements. One group was formed by people most closely involved in the project and represented practice and research, one group was formed by the steering committee and one group with people randomly selected from the citizen panels. Welfare of the hens was evaluated with the FOWEL model as developed and reported by Mol *et al.* (2006). FOWEL uses a description of the production system as input and produces a welfare score as output. The economic evaluation at farm level consisted of calculation of production costs per egg.

Robustness and naturalness

An additional aim of the project was to articulate – in verifiable and concrete terms – two concepts that play a central role in societal debates on the future of animal husbandry: *robustness* and *naturalness*. *Robustness* generally points to the need of reducing the vulnerability of both the animals and the production system as a whole. According to Verhoog *et al.* (2003) *naturalness* can refer to at least three different notions: not using chemicals, ecological principles, and respect for the integrity of life. In this case, 'the natural state' of animals before domestication was added. Although both concepts are meaningful and have a positive connotation, they are difficult to define precisely. One might even argue that exact definitions are impossible, since both concepts are inherently value-laden. These values may differ between individuals. Considering this, we translated these concepts in such a way that they expressed and combined several of these meanings, while being concrete enough to be used as leading principles in the design process. They should be specified further in localized material realizations of these designs (Radder, 1996).

The concept of *robustness* was operationalized as the extent to which a production chain, a production system or an animal can withstand internal or external disturbances (see also Ten Napel *et al.*, 2006). A proven strategy to increase robustness in this sense is to enable systems to cope and learn from disturbances. Requirements were formulated as "enhance system's adaptational range" and "allow for internal disturbances and external influences within the adaptational range". The concept of *naturalness* was operationalized as the requirement of fulfilling the *ethological* needs of animals (referring to the notion of the 'natural state' of animals prior to domestication), as the requirement (preference) to select solutions that utilize self-organization (for instance, of animals) for functions to be fulfilled in the system (Bos *et al.*, 2003), referring to naturalness as 'ecological principles', and as the requirement of preventing the need for non-reversible interventions like beak-trimming, referring to naturalness as respect for the integrity of the animal (Verhoog, 1997).

Results

The results presented below focus on (1) the strategic problem definition, (2) the fundamental needs of the laying hen, farmer and citizen/consumer and the resulting Brief of Requirements (BoR) as a basis for a new husbandry concept, (3) the key functions that have to be fulfilled, (4) a description of two design concepts, and (5) some results of the evaluation.

Strategic problem definition

The strategic problem definition was the major outcome of steps 1–4 of the structured design process (Table 2). The final version of the strategic problem definition was phrased as follows: A new husbandry concept should:
1. Allow the animal to have a productive and happy life;
2. Have a positive societal image that is true to reality;
3. Have an outdoor access that meets the various concerns of stakeholders in the egg-production sector;
4. Be robust at the level of the production system, including lower system levels.

These priorities guided the innovative efforts of the project. Other reasonable requirements, like economic viability, environmentally sound production and food safety were not discarded, but were taken as requirements that should equal the performance of current systems but not necessarily exceed them.

Figure 3. Two visual expressions of demands of Traditional Bourgeois: 'respect for lower organisms' and 'future vision with reference to the past'

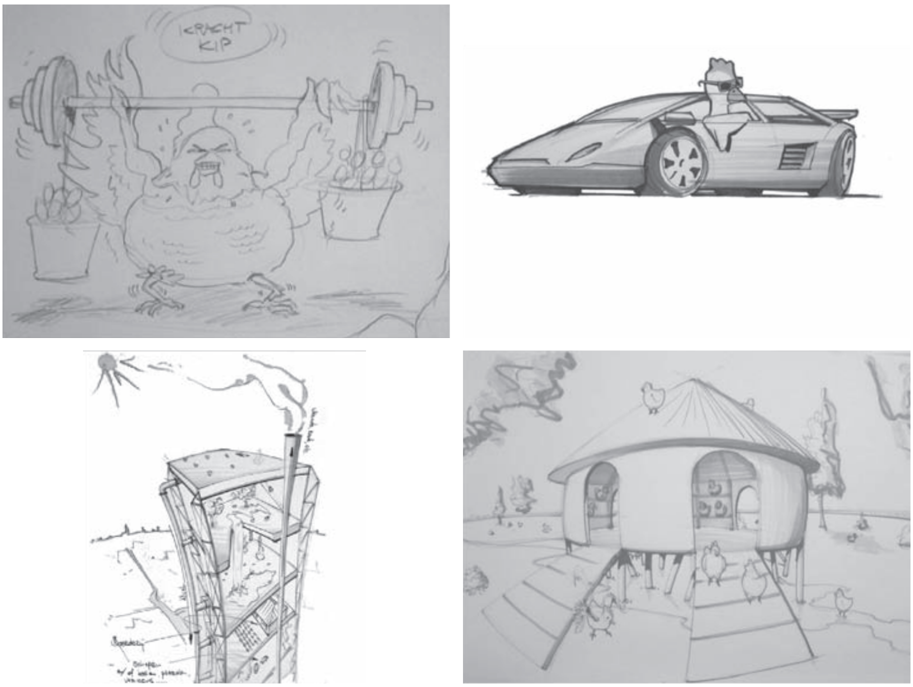

Figure 4. Four visual expressions of demands of Cosmopolitans: 'the fitness layer', 'the fast Ferrari chicken', 'high-tech housing system', and 'round indo-like hen house above a river'.

Needs of citizens, farmers and laying hens – the Brief of Requirements (step 5)

Citizens/consumers

Our presupposition that a plurality of values and visions exists among human stakeholders proved to be right. For instance, within the citizen groups a clear-cut differentiation could be made between people who identified themselves with laying hens when asked for the ideal way of keeping hens, and people who maintained the distinction between themselves and the animal, but expressed their moral obligation to treat animals respectfully and well (Goenee & Le Goff, 2003). So animal welfare as a general concept means different things to different groups of citizens. The *Traditional Bourgeois* in the Mentality-model expressed their wish for a caring and respectful treatment with a dominant reference towards traditional farming, which is perceived by them as paradigmatic for a respectful relation between men and animal (Figure 3). On the other hand, for *Cosmopolitans*, animal welfare means a dynamic life combined with a sufficient amount of privacy. In this group a very close relation with the ideals for their own life could be identified, witnessing for instance their strong emphasis on wellness and health, which also is a strong trend in current consumer behaviour (Figure 4).

Poultry farmers

Three different roles of the poultry farmer were identified that differentiated his needs. First, he is an *animal keeper* who wants to take care of his animals in the best way possible. Second, as an *entrepreneur* he is forced to manage his farm economically. Third, he (or his co-worker) is a *labourer* himself, who carries out the work on the farm. In these different roles he is confronted with different and sometimes conflicting needs. For instance, as an animal keeper he does not like to trim beaks but his interest as an entrepreneur to obtain production goals sometimes forces him to do so. By differentiating and abstracting these needs we were able to overcome these contradictions in certain respects. An example is the problem of floor eggs. Only after intense discussion farmers admitted that floor eggs are a serious problem, not in terms of effects (the number of floor eggs can be controlled to less than 1%), but in terms of labour requirement (high during the first months after starting laying), risk management (hard to predict) and social effects (shift in working hours to early in the morning). So the problem of floor eggs was not seen as a conflict of interests between laying hens and farmer *per se*, but as a design flaw of current free-range systems, in which neither the need of the laying hen, nor the need of the poultry farmer as labourer or entrepreneur was met.

Another example is the robustness of the system as a whole. From the interviews we learned that at least some poultry farmers were perfectly willing to give in on production efficiency (one of their goals as an entrepreneur) in order to have a system that is less prone to unexpected calamities, something they would rather avoid in their role as labourer and family member. A short overview of the requirements of a poultry farmer is given in Table 3.

Table 3. Indication of requirements (not quantified here) of a poultry farmer in his role as producer (entrepreneur), animal keeper and worker (labourer).

Role of poultry farmer and requirements	Example or explanation
Producer	
Continuity of business	Business development
Product quality	Meet market demands and legislation
Income and profit	In accordance with amount of labour and risks
Undisturbed production	Limited number of floor eggs and diseases
Keeping productive hens alive and healthy	Sufficient options within legal boundaries
Disposal of rest material	For instance, manure and dead animals, in a legal way
To produce eggs	As many as possible per hen and of high quality
Animal keeper	
Socially justified animal keeping	Meeting demands of welfare and environment
Act responsibly	In accordance with own and societal values
Openness of the production system	Production system is visible for other people
Dignified farmer	Maintain self-respect
Contact with, take care of and work with animals	(clear in itself)
Keeping animals healthy and protect them	Equal to basic requirements of the laying hen
Allowing animals to perform natural behaviour	Equal to basic requirements of the laying hen
Worker	
Income	In accordance with amount and quality of labour
Job satisfaction	Appreciation by others
Undisturbed and manageable production	Limited production disturbance, sufficient solutions
Job security	Stable sector
Job satisfaction and work convenience	Especially ergonomic demands
Social contact and freedom	Normal social life besides work
Efficient, safe and healthy working environment	Restrictions on air quality, noise, heavy loads

Laying hens

By defining the ethological needs of laying hens, a minimum level for animal welfare was attained, allowing for the claim that laying hens will not be ‘unhappy’ when these needs are met. The general ethological needs of laying hens were defined in terms of ranges, since there are considerable differences in needs and requirements among individual birds within a flock of laying hens. For instance, there are individual preferences for different types of laying nests. Generally, birds prefer a sheltered, mouldable nest. By acknowledging a range of individual preferences, and offering different types of nests (individual or group) at different levels (above or at ground level) and different types of litter the problem of floor-laid eggs might be solved.

Based on the ethological needs and their variation in time (e.g., daily rhythm) and place (and interactions and synchronization), total space requirement for all functional areas (related to key functions) of a group of hens was assessed to amount to 2214 cm^2 per animal. This is considerably more than space allowance in current systems (e.g., 1111 cm^2 in single- and multi-tiered aviary systems, 750 cm^2 in furnished cages and 500 cm^2 in current cage systems). Essential to this was the spatial split between functional areas (no overlap) and direct accessibility of all facilities.

The Brief of Requirements

The resulting Brief of Requirements (BoR) consisted of a few hundred entries, categorized according to the needs of the different actors involved. The complete BoR (Anon., 2005) can be obtained from the authors and at <http://www.houdenvanhennen.nl>.

Identification of key functions linking needs with requirements

Table 4 lists the identified key functions that link the most important needs of the actors laying hen, farmer and citizen with their requirements. Especially the new requirements from citizens are linked with the key functions to show three typical effects. First, many requirements from the BoR of the citizens could be linked with current functions that have to be fulfilled for the ethological needs. Requirements like 'sufficient facilities', 'fresh air', 'rest' and 'natural elements for feed and facilities' were additional and not contradicting existing requirements (from e.g., the laying hen) for current functions. A dust-bathing area provides possibilities for implementing natural solutions and expressing naturalness. Sometimes consumer requirements were even close to trivial economical requirements of farmers, as in the case of 'efficient use of space'. This category of requirements had a relatively small effect on the solutions that met the BoR.

Secondly, some requirements matched with current functions, but put these functions in another perspective. Consumers' requirements regarding 'arrange and manage functional areas' (e.g., open system, visible hens) meant a structural change whereas this function in current systems is mainly determined by economical and functional requirements of farmers. Also the farmers' responsibility for animals shed another light on his function as a labourer to take care of animals. Various requirements could only be matched with the more general function 'make complete design' to fulfil the need for societal acceptance. This category of requirements had a major impact on the solutions that met the BoR.

Thirdly, also new key functions were identified. As in the last example, specific functions were identified to fulfil the needs of the farmer in his role as labourer, manager and entrepreneur, and link them with specific requirements of the citizens. The function 'supply of water' was split into 'transport water' and 'drinking facility' to match this with the requirement of open and running water. Also the new functions 'provide visiting facilities' and 'provide information' were crucial to fulfil the need of citizens to understand husbandry systems.

These three effects show that compatibility in the design process can be arranged at the level of requirements, at the level of existing functions or by defining new functions.

Table 4. Actors, their most important objectives (needs), key functions and newly identified requirements from the Brief of Requirements.

Actor	Objective needs	Key functions	New requirements [1]
Laying hen	Ethological needs (see below)	Fulfil ethological needs	Naturalness
			Treat animals respectfully (TB)
			Sufficient animals to perform individually preferred behaviour (CP)
	Need for suitable living environment	Provide space	Outdoor access of hens (PM & TB)
		Control indoor climate	Open character of the production system (C)
			Fresh air for hens, but no draught (C)
	Need to map and explore	Provide foraging area	Hens visible for passer-by (C)
	Need for feed and water saturation	Supply feed	Varied food, including natural elements like insects (PM)
		Transport water	Open and running water (C)
		Supply drinking facility	
		Supply scratching facility	Hens visible for passer-by (C)
	Need for health: absence of chronic pains and stress	Keep hens healthy	Care and attention for the animals (TB)
			Limited stress for hens (C)
	Need for movement:		
	running, turning , fluttering	Supply space	Sufficient space (total of 2214 cm² per hen)
	maintain feathers [2]	Supply dust bathing area	Natural solutions / expression of naturalness (C)
	comfort behaviour (e.g., wing flapping, stretching legs)	Supply space	
	Need for social interaction	Set system characteristics	Limited group size (C)
	Need to rest	Provide perches	Hens' need for privacy (HM)
	Need for safety	Supply hiding facilities	Solid and safe living environment (TB)
		Able to flee	Natural elements like trees and bushes (PM)
	Need to lay eggs	Provide laying facility	Hens' need for rest (CP)
	Need for accessibility of facilities	Arrange and manage functional areas	Spatial lay out according to daily rhythm of the hen (L, C)
			Spatial separation of functional areas (L, C)

Table 4, continued.

			Open system and visible hens (C)
			Continuous accessibility of all facilities (PM)
			Efficient use of space (PM)
Farmer	Needs of a labourer	Take care of animals	Farmer's responsibility for animals (TB)
	Needs of an animal keeper	Provide management facilities	Minimal interference by human (TB)
		Control husbandry system	Minimal interaction between farmer and animals (PM)
	Needs of an entrepreneur	Generate income	
Citizens	Need to understand the system	Provide visiting facilities	
		Provide information	Specifically on behaviour of the hens (C)
	Need for naturalness and transparency	Make complete design	Different ages of hens together, including rearing (C)
			Traditional image of farming (TB)
			Friendly appearance with organic shapes (C)
			For outsiders recognizable as egg production facility
			Presence of natural and living elements (C)
Citizens and farmers	Need for robust systems	Increase system's adaptational range	Increase choices for laying hens (e.g., functional areas) (L, PM, CP)
			Decrease amount of feedback that needs technical intervention (PM, F)
			Prefer self-organization to fulfil other functions (F, PM, CP)
		Allow for internal and external disturbances	Use location-specific pathogens to build up immunity (F, L, PM)

[1] L = laying hen; F = farmer; C = citizens in general; CP = cosmopolitan citizens; PM = post-materialistic citizens; TB = traditional bourgeois.
[2] *Maintain feathers* is not strictly a need for movement only, but for practical reasons classified here.

The design concepts 'Roundel' and 'Plantation'

Two significantly different design concepts were elaborated into designs for husbandry systems, one with (*The Plantation*) and the other without (*The Roundel*) an outdoor run. Both concepts synthesize the ethological needs of laying hens and the needs and requirements of farmers, and appeal in form and function to specific classes of citizens/consumers. The third concept, a relatively large-scale (over 5000 hens per unit) mobile housing system, was not elaborated.

The Roundel

The Roundel (plan view, Figure 5) resembles a large round cake from which one piece is missing. A large two-stories-high loft consisting of 12 segments covered by a roof but open to all sides surrounds a central management area. This area provides space for the egg-collecting system, as well as storage space for the eggs, feed and other items. Ten of the 12 segments consist of a pen area and a foraging area and are used for the housing of 3000 hens each. Each segment houses one group of hens.

Its name, Roundel, conveys values like robustness and security. The space is used in a compact way, but functional areas are separated for easy access by the hens. At the same time, its radial form improves accessibility and overview by the poultry farmer, while the round yet robust shape is chosen to appeal to the class of citizens who stress the importance of safety and care (the *Traditional Bourgeois*). At the same time, the diversity of the inner open and private space, which includes a diversity of materials for exploration, scraping and dust bathing, appeals to another class of citizens, the *Cosmopolitans*, and allows for individual variation of needs within the flock.

Each of the 10 segments has split levels for the foraging areas (cross section in Figure 5). There are two foraging areas, one in the outer ring at ground level and separated from the neighbouring segments, and one above the central ring that can also be utilized for dust bathing, food searching and exploration. Both areas are enriched with a thick layer of dry litter material and with all sorts of plants, and during day time grain seeds are scattered a number of times for a few minutes, using an automated rotator. Daylight reaches the loft area and the ground segment through large windows in the ceiling, and through the sidewalls made of netting, which also allow for ventilation. There are two climate zones. The climate in the pen area is relatively stable at 20°C, whereas the climate in the foraging areas varies with the amount of sunlight, the outdoor temperature and wind. However, extreme temperatures do not occur.

The Roundel is designed to provide much protection for the hen but also for the poultry farmer. The hens have no contact with birds from outside the system, and foxes and vermin can easily be kept outside. So the hens are not exposed to extreme conditions. A type of laying hen that has a slightly lower requirement for foraging and exploring, but that prefers resting, continuity and the expression of behaviour like preening or dust bathing is best suited to this system.

The Plantation

The Plantation (Figure 6) is spatially characterized by two lightly curved lines of

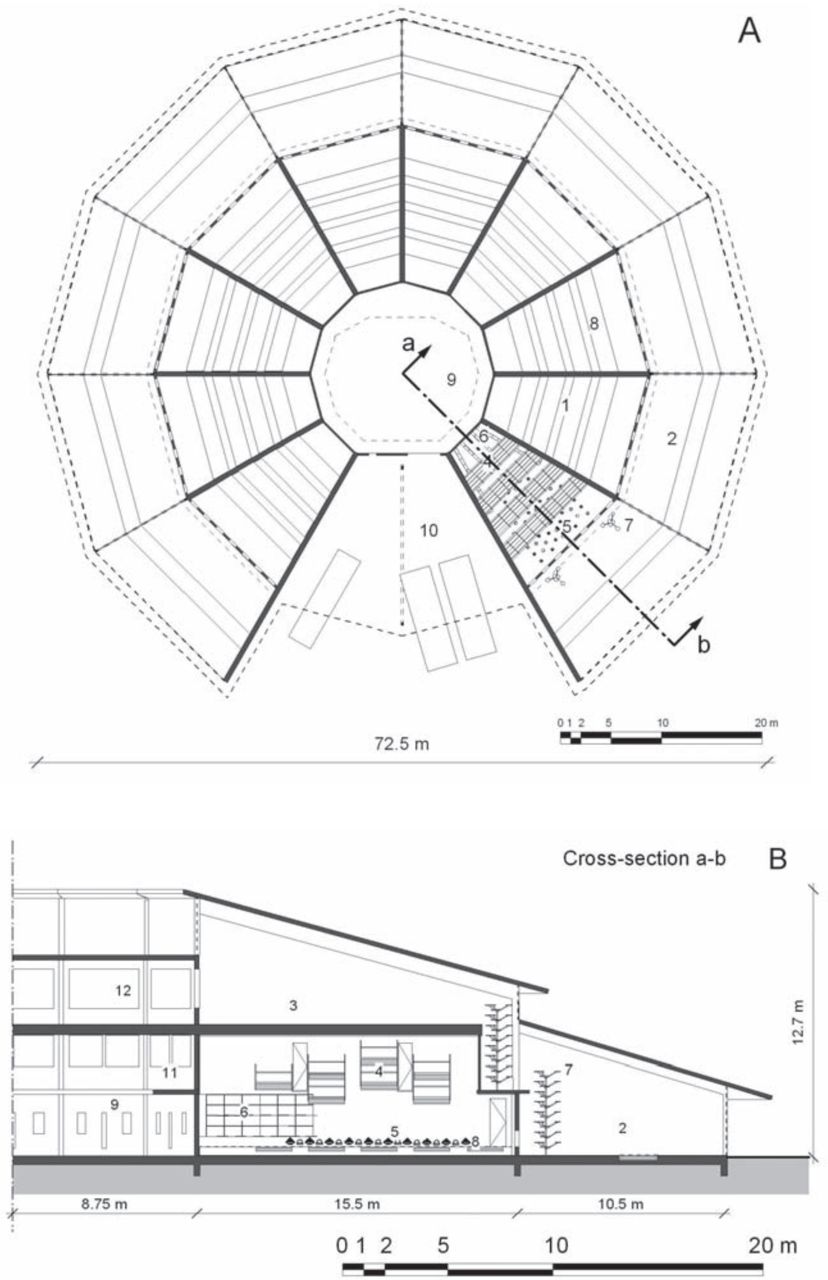

Figure 5. Roundel design. Top view (A) and cross-section a-b of one segment (B). 1: unit for 3000 hens; 2 & 3: foraging areas; 4: perches (for resting) over manure belts; 5: water and feed supply; 6: laying nests; 7: artificial trees; 8: manure belts at floor level; 9: room for collecting eggs; 10: expedition; 11: visitors and control gallery; 12: technical installations. (drawn by JvR Architectuur)

buildings cut into the landscape and enclosing a large inner yard area. This ensemble is positioned amid several hectares of land with fruit trees, willows and maize fields, which are part of the system. Its name, Plantation, refers to the former large colonial estates where living, working and recreation were combined. Characteristic for its design is the combination of natural and technical elements, and the emphasis on exploration and self-sufficiency. It is meant to appeal to a class of citizens, the *Post-materialists*, who value the potential of nature, while being open and interested in creative linkages between sophisticated technology and organic and ecological processes. Another group of citizens, the *Cosmopolitans*, may be pleased by the choice-freedom for the hen, the range of possible activities and the availability of privacy.

The inner yard of the Plantation forms the central area of the system. In case of rain a sliding roof covers the central area within minutes, maintaining it as a suitable foraging and exploration place for layers. The inner yard contains a lot of greenery and distraction for the hens, such as grains, green waste and cut wood from the outer area. The inner yard plus the buildings already satisfy all ethological needs of the hens.

The large outer areas on both sides of the buildings have a dual function. Tree crops and maize can be grown there, providing the hens with ample opportunity for

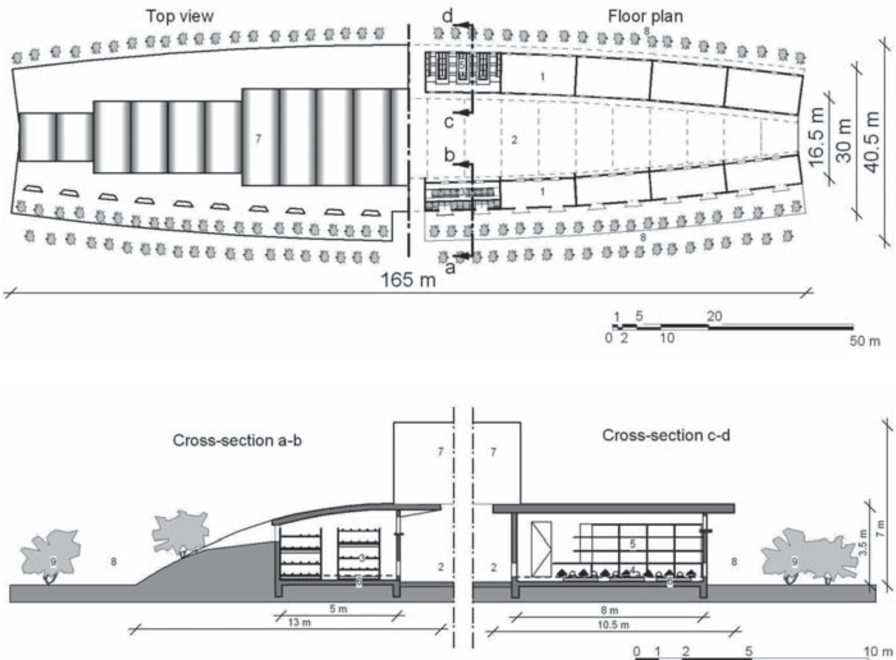

Figure 6. Plantation design. Top view, floor plan and cross-sections of the two houses of one unit. 1: unit for 3000 hens; 2: inner foraging area; 3: perches (for resting) over manure belts; 4: water and feed supply; 5: laying nests; 6: manure belts at floor level; 7: roof of semicircles covered with plastic foil that can be opened and closed; 8 and 9: outer area with shrubs & trees. (drawn by JvR Architectuur)

exploration. Under the safe cover of this vegetation the hens can move far away from the inner yard and buildings. The hens in turn may be useful by eating weeds and hunting insects.

The two lines of buildings consist of units of 3000 hens that are not separated at the inner yard. Both lines have their own function. On one side there is a covered resting space, on the other side the hens have access to facilities to eat, drink and lay eggs. Activities such as resting, eating, egg laying, foraging and exploring are functionally separated, but are interconnected by logical routes. The two pieces of land of at least 3 ha on both sides of the buildings have a dual function: crop production and exploration. The hens can look for their own food, but there is no protection from foxes or birds of prey. These areas can be used alternately, in order to let the soil recover and grass and weeds re-grow.

The Plantation very well suits a type of hen that is more inquisitive, less easily frightened and that remains alert. The hens may be a little heavier and will have a greater feed intake to compensate for the climatic variation in their environment. The raising of hens for future laying hens also takes place on the farm. The young animals will be separated from the adults and get gradually more yard space. This has several advantages: the hens experience no stress from transport or the change in living environment. By teaching them at an early stage how to use the yard, they will concentrate their pecking behaviour on the ground rather than on other hens. As the hens are gradually exposed to farm-bound diseases, they will be able to adapt to local circumstances by building up a strong immunity at an early age (Savelkoul & Tijhaar, 2007).

Evaluation of the Roundel and Plantation

The welfare evaluation of the Roundel and Plantation yielded a score of 210 and 204 points respectively, out of 246, compared with 181, 163 and 93 points for an organic, a multi-tiered aviary system and furnished cages, respectively.

The costs of table egg production in the Roundel and Plantation were estimated to be 20 and 34% higher than for furnished cages. Compared with a multi-tier aviary or free-range system the increase in costs amounted on average 5 and 17%, for the Roundel and Plantation, respectively. However, production costs would still be 40 to 50% lower than for organic table egg production. Investment costs of buildings and machinery were higher for both designs, but accounted only for some 10% of the total costs. Especially the expected increase in feeding costs (higher feed intake) and lower numbers of produced eggs were responsible for the higher costs.

Discussion on the integrated design approach

The discussion will focus on two aspects of the integrated design approach: (1) the identification of a sustainable state or development of complex food production systems, and (2) the approach in relation to innovation theory and successful implementation of the results.

Identification of sustainable development of complex food production systems

Adaptation of current food production systems is necessary to improve sustainability, e.g., animal welfare or a reduction of environmental impact, but generally leads to higher production costs. Often, the only solution to such perceived conflicts of animal, societal and farmer interests is a trade-off or weighing of interests in the design, guided by the constraints set by what is seen as the external environment: market, regulations, and public pressure. This way of dealing with conflicting interests in design processes is unsatisfactory, and rarely innovative. It is unnecessary as well, since the unwarranted assumption is that these interests are one-dimensional and homogeneously shared by all representatives of a specific group of stakeholders. This does not take into account the plurality of values and goals within these groups.

With the integrated design approach we took a closer look at what really drives farmers, citizens and consumers in their judgements, actions and behaviour and used the plurality within these groups – varying consumer groups, varying types of farmers – and identified specific characteristics of laying hens for specific situations. By identifying their needs rather than their interests, and the differentiation of requirements we saw ample opportunity for a fruitful reconciliation, as shown by Table 4 and the two designs. In general, this methodology boiled down to a more concise investigation of the whys (reasons) behind the wishes, or the more fundamental needs behind interests at first sight. In the case of citizens/consumers this led to more differentiation amongst Mentality groups in their actual values regarding husbandry systems for laying hens. Despite the negative stories about the poultry sector, the results also show a lot of positive associations with poultry and the husbandry systems of poultry, although in variegated ways. People not only mentioned the more traditional, pastoralist clichés, but also sketched perspectives that allow for and are compatible with modern production circumstances. This also led to the identification of more continuity between their ethical and esthetical aspects of judgement on the one hand, and their views on the 'good life' on the other. The latter could be related to specific differences in lifestyle among these groups. In this way, we were able not only to distinguish different views on the meaning and value of animal welfare and naturalness, but also to establish a closer link between the cognitive and emotional evaluation of husbandry systems by citizens. As a result, a closer link could be established between their role as a citizen and their behaviour as consumer, thereby relaxing the often perceived tension between these two roles (Dagevos *et al.*, 2005). So results like those of our citizen panels should not be treated exclusively as varying expressions of ethical concern. These expressions also contain valuable information for communication with consumers in a truthful way about these husbandry systems and the development of different products for different markets. It seems plausible that consumer values can be positively connected with quality traits of the primary production. This will help the poultry sector towards a sustainable development that is socially acceptable and economically feasible.

The Brief of Requirements (BoR) played a pivotal role in the integrated design approach. Its set-up forced us to quantify as much as possible all requirements of the hen, the farmer and the consumer/citizen. It helped to establish a fruitful interaction and convergence of scientific and experiential knowledge on the one hand, and practical and tacit knowledge of stakeholders on the other. The set-up of the BoR turned out to be useful for analysing and integrating very heterogeneous needs and requirements, while keeping the process structured and offering a means to communicate with relevant stakeholders. However, the BoR was not especially appropriate for addressing qualitative characteristics of the design, as was the case for the requirements of the citizen groups (Table 4), although it resulted in a tangible and accountable product. The ethological needs of laying hens and their requirements created a set of minimum standards the new designs had to meet. The combined effect of this method was that the needs of the different stakeholders involved were identified and analysed in more detail than commonly applied in practice. This in turn allowed for a positive and fruitful convergence of specific needs, circumventing the paradigmatic idea that the development of animal husbandry systems is essentially a trade-off between conflicting interests of the farmer, the animal and society. Of course, it is by no means said that in this project these conflicts were resolved all at once or that all aspects of sustainable development were incorporated in the new concepts (related to societal, environmental and economical aspects). The strategic problem definition only showed the specific focus and represented the views of the stakeholders involved. On specific topics, however, it was shown that it is possible to think and design beyond these conflicts by eliminating and creating compatibility at the level of requirements and functions.

The approach in relation to theory on innovation and implementation

The integrated design approach aimed to initiate and stimulate a sustainable development of the laying hen industry in the Netherlands. The approach as described in this paper offers a solution for (1) the changing role of the Dutch government in the development of a sustainable agriculture (traditionally direct funding of mono-disciplinary research and implementation of knowledge and systems through legislation), (2) finding the balance between short-term action and long-term sustainability goals, and (3) a meaningful interpretation of terms in the political and societal debate about livestock farming. During the last decades, innovations and changes in Dutch agriculture were mainly driven by increasing standards laid down in national and EU legislations (especially environmental and animal welfare issues) and quality control systems, either initiated by the sector itself (e.g., 'Integrale Keten Beheersing' – Integral Chain Control), or by retail organizations (Anon., 2007c). The success (and existence) of the former innovation system of Dutch agriculture, the so-called OVO triad (a Dutch acronym for the triad research–extension–education) came to an end in the early 1990s. This triad generated knowledge and technology through innovative agricultural research and disseminated it to agricultural practice through education at agricultural schools as well as through extension services to farmers. During the 1980s the classical institutional arrangements (the OVO-triad and the iron triangle of the ministry of agriculture, agricultural branch organizations and agricultural specialists in parliament; Bekke *et al.*, 1994) were opened up under the pressure of outside actors like non-governmental organizations, citizens and their echoes in parliament (Wisserhof, 2002). These outside actors finally obtained a place at the table of agricultural decision-making.

The integrated design approach combined insights of several methods to deal with multi-problem situations like the case of table egg production in the Netherlands. From the theory of sustainable technology development (STD) we derived the insight that one needs a common orientation that outlines a longer-term vision. Such future visions help stakeholders to get rid of the perceived limitations of current structures and practices. We achieved this by formulating a strategic problem definition embodying the challenges as well as the ideal situation. Although it must be admitted that contrary to the theory of STD, the fundamental question of the rationale of the egg production sector, being the function to produce eggs for human consumption, was not raised. From the theory of Strategic Niche Management (SNM; Kemp *et al.*, 1998; Hoogma *et al.*, 2002; Roep *et al.*, 2003) we adopted the notion that innovation takes place in specific contexts that are temporarily shielded from the normalizing influence of the existing socio-technical regime. Our emphasis on the adaptability of the results of the project to specific needs and circumstances, notwithstanding the basic requirements in the BoR, should be seen as an application of this thought. Finally, from Interactive Technology Assessment (ITA) we adopted the fundamental idea that needs should be separated from interests. If a problem is framed in terms of conflicting interests, and if these interests are taken as given and unchangeable over time, chances are great that a suboptimal solution is reached. Actually, in the Netherlands this often is the way debates on the future of animal husbandry are structured. Essentially, discussions should be based on needs and not on solutions. Needs can be seen as interests free from strategic anticipation of external forces. This requires a continuous reflection on the assumptions and starting points of current systems that guide actors' thinking and behaviour (Bos, 2008). The synthesized approach presented here is meant to do exactly this, and will be worked out in greater detail in the future as 'Reflexive Interactive Design' (RIO; Bos *et al.*, 2008).

Research and development in a highly contested area like animal husbandry, have to deal with a multiplicity of challenges at once, originating from economy, ethics and technology, and should be treated as a whole. The integrated design approach is therefore not exclusively focused on the design of technical solutions and the subsequent 'add on' of qualities that have to satisfy social requirements (like values and aesthetics). Integration implies a higher degree of coherence between the 'technical' and the 'social'. As a consequence, the new concepts of husbandry systems (the Plantation and the Roundel) as proposals for technological objects are just part of the result, and their raison d'être is not primarily to be realized and adopted as such, but to function as a vehicle for change in the production sector involved. The process of design, formulating the strategic problem definition, the BoR and the stories told along the way are meant to contribute at least as much as the concepts themselves to the actual occurrence of system innovations within the sector towards sustainability. The project indeed served as a trigger for new initiatives and a series of 'niche experiments' (Wisselink, 2005; Bijleveld, 2006).

Concluding remarks

The integrated design method worked out well for the identification of a meaningful interpretation of sustainability of a complex heterogeneous production system in a food chain, resulting in an overall Brief of Requirements and two innovative design concepts. Moreover, application of the design method learned that participation of various stakeholders in design activities can play an important role in catalysing discussion between society and agriculture. This was exactly the aim of the project. Not only to influence and increase the knowledge of the poultry sector and the various interest groups, but also to have an impact on their attitude towards animal production and other parties and their willingness to take action towards the development of sustainable egg production in Europe. The current combined initiatives and actions by various parties can mean a new starting point for sustainable table egg production in the EU.

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