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*Published in:*
Interaction Design and Architecture(s)

Published: 01/01/2018

*Document Version*
Publisher's PDF, also known as Version of record

# The Participatory Design of Tools: Foreseeing the Potential of Future Internet-enabled Farming

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**Abstract.** This paper describes the use of functional models in a participatory design process to facilitate user involvement in complex system design. The particular case study presented here is the design of Future Internet-enabled farming system to address the global food chain challenges. Taking an end-user perspective during the development of systems and infrastructures in order to assist people in their work and everyday lives sets new challenge for complex system design. In extending the use of functional models by adopting the human factors engineering perspective, we show how future practice was made tangible and subject to the value estimations of a variety of end-user groups. In the food chain related development project, functional models facilitated the creative agency of the food chain actors and enabled a participatory design process in which the agricultural engineers and the food chain actors collaborative worked on a vision of future farming.

**Keywords:** Participatory design, functional modelling, complex systems, user involvement, values, human factors engineering, Future Internet and food chain activity

## 1 Introduction

Designers developing systems and infrastructures for assisting people in their everyday life and work face a high degree of complexity [1]. In developing a system or infrastructure, it should be called to mind that the relationship between a new design and a given activity is a co-evolving one [2]. The activity sets requirements for the designed technology and, when implemented, the new design in use produces a shift in the activity itself. Thus, due to this (task-artifact cycle), a static state between design and the activity it addresses, is never reached and the activity constantly evolves sometimes even unexpected ways. In order to cope with this continuous cycle of mismatch (with design being always one step behind), and to enable the formative but also deliberate design of tools and their future use, future demands should be comprehended in more generic terms. In design, a myriad of interests and objectives of stakeholders also need to be addressed. Moreover, the continuous advancement of technology, the growing demands for optimized operations and the increasing need for environmentally and socially responsible solutions all present new opportunities and challenges that need to be taken into account in system design [3][1]. The complexity of a modern work system cannot be described by a single rule and its characteristics are not reducible to one level of description. Thus, a multitude of perspectives is needed for the design — the human factors engineering (HFE) perspective [4, 5] represents an important one of these perspectives. For human factors (with a special emphasis on human and social aspects) to take a more active role in the design of complex systems requires adapting oneself to a designerly way of producing knowledge [6]. In other words, that design knowledge is produced by integrating different expertise in the context of applications in order to find solutions to practical problems of relevance to specific stakeholder groups or to society at large [7].

Active and early user involvement has been proven to be valuable in improving design [8]. User involvement is seen to resolve ambiguity about the design task at hand [9]. It is also seen to produce more valued solutions [10]. It is therefore not surprising that much research in design has focused on how to address the needs and preferences of users as well as on how to reassert the user's role and involvement during development. A number of tools and methods from outside design – for example, from ethnographic field observations – have been appropriated for design in order to aid designers in understanding users and the use context [11, 12]. That said, how to best involve users in development processes remains very much an ongoing discussion, and perhaps particularly so in the case of designing complex systems.

A prerequisite for user involvement is that users can comprehend the future system and how it may affect work practices. In forming an understanding about the future system in use, users can then express informed opinions and form realistic expectations. In this paper, we address user involvement in complex system design, reporting on the use of functional models for jointly examining the operational qualities of a new system and as a descriptive tool to facilitate active user involvement in design projects. In reporting on the development of a new work system, we outline how functional models can aid designers, technology developers and end-users to form a conceptual understanding of a future system in use during design.

Functional models are structured representations of the functions (purposes, activities, actions, processes and operations) within a modelled system or subject area [13]. Traditionally, functional models have predominantly been used within technical development to study and validate the technical quality of systems in different operational situations. In short, functional models provide illustrative representations that help technology developers view the system from an operational perspective, thereby facilitating the discovery of information needs, opportunities and demands within a development context. Even though functional modelling has been found to be useful in many technically oriented fields of design, within engineering it still does not represent the mainstream.

The context for our study is the Future Internet (FI) and the design of a food chain application for food production, in other words, a smart farming system. The smart farming system aims to optimize farming with regard to global food chain challenges, including food safety, environmental issues, the ethical and sociocultural aspects of food production and consumption. It is an information and management system that supports (the collaborative human and machine control of) modern farm production and widely exploits the possibilities of FI-based smart services. Through active user involvement in the development process, we exemplify how functional models were used to help food chain actors to envision the purposes, higher-level structures and functionalities of the yet-to-be designed system and its use in the new information-intensive farming practice.

Drawing on earlier analyses of farming work [14], a set of functional models was developed by human factors specialists in interaction with agricultural engineering experts. These models were then used as a starting point and tool in involving food chain actors during the concept design. In specific, through the development of functional models a system that was not yet available in the real world was made tangible through modelling. Discussing the developed models with food chain actors in a series of panels and workshops provided early insights into their needs and expectations for the future system. The resulting understanding was summarized in user experience (UX) goals and domain-specific requirements, which were integrated in the development process.

In outlining the functioning of the models in the development process, we begin this paper by conceptualizing the benefits of functional modelling beyond its technical application, in other words, the facilitation of user involvement and the participatory design (PD) process. Next, we present a food production related case study. Specifically, we describe how a variety of food chain actors were involved and how they gave their comments and improved the proposed system. We focus our report on how food chain actors' evaluations of the value of the proposed FI-supported smart farming system helped the agricultural engineering experts to further refine the details and the technical base of the proposed solution. We end the paper by reflecting on our experiences of using functional models as a basis for user involvement, positioning our experiences within participation in the design process.

## 2 User Involvement in Complex System Design

With *complex system design*, we refer to the development of a sociotechnical system with a high degree of interdependency between its components, parts and actors that collectively produce the desired behaviour [15]. Designers and technology developers are increasingly challenged to manage the growing complexity of interactions, tightly coupled functions and technical issues in designing systems. In doing so, the social aspects and implications of a system in practice are at least as important as its technical ones. To this end, as the scale and complexity of systems increase, there is also an increasing need to actively cater for human factors and organizational understanding during development. In specific, there is a pressing need to carry out systematic efforts to integrate human factors, including participatory processes empowering end-users and other relevant actor groups, in the design of complex sociotechnical systems. However, the human factors engineering approach and methods need to be adapted to the logic of design in a sense that the actors within the designed system (i.e. the end-users) are no longer only observed from outside and from a distance. The actors are instead addressed by actively involving them as part of the actual design process in a collaborative manner [16]. These efforts need to extend over the whole lifetime of a system and cover everything from requirement elicitation, concept development and iterative maturation of solutions, to the implementation and appropriation of technology in use.

### 2.1 PD and the empowerment of users

In both design theory and practice, there is a long-standing interest in involving users when designing. An interest in involving users may be found in a number of different movements and practices for design. In the PD movement, a need to actively acknowledge the voice of users and empower them in the decision-making and design of industrial work systems was a defining characteristic from the outset [17]. Grounded in the Scandinavian labour union tradition, PD argues for a democratization of the workplace [18], allowing those affected by a design to have their say during development [19]. In this vein, PD has been an early advocate of acknowledging social aspects in work contexts.

A more contemporary stand on PD [20] has made an effort to expand its scope and has purposefully aimed to dilute its earlier dominant labour orientation, in other words, it aims to influence the power relations at work places. Instead, these new conceptions of "who" matters in design have led to expectations of greater enfranchisement and new alliances for change that are aiming at, for example, solving real-life problems [21, 22] and more extensively accounting for a lifecycle perspective [23], as well as acknowledging end-user innovation and user appropriation as natural parts of system evolution and design [24]. Muller and Druin [25] referred to Bhabha's [26] argument (made in the context of colonization) about the existence of a so-called third space when comprehending PD methods and practices in interaction design. According to Bhabha, the third space – manifested in the overlapping boundary region between two domains, for example, between the representatives/peoples of two different cultures – contains an unpredictable and changing combination of the attributes of each of the two bordering domains. Thus, through continual negotiation and the creation of identities, the representatives of the two domains become part of a new culture – that is to say, part of the third space or hybrid space – which is fruitful grounds for the exchange of knowledge, mutual learning and gaining new insights. Building on this idea, Muller and Druin see that contemporary participatory processes should focus on enabling the creation of third spaces in which the representatives of the two domains: in the case of participatory system design, the designers / technology developers and the end-users could meet, exchange ideas and perspectives, and engage themselves in the design activities.

An interest in user involvement is also visible in user-centred design (UCD). By actively involving users in development, UCD aims to give extensive attention to the needs, wants and limitations of the end-users of a product, system or service [27]. In essence, defining and setting the right user requirements from the very beginning of the design process is considered to assist in designing products that better correspond with users' abilities and needs and, by extension, are more usable. Similar arguments have also been made in fields such as human–computer interaction (HCI) and information systems (IS), as well as in emerging fields such as computer supported cooperative work (CSCW) and experience-centred design [28]. All these movements share an interest in understanding users, use contexts and how both understanding from and about users can inform and strengthen social and contextual understanding in design.

## 2.2 Tools and methods in PD

As the knowledge of users should play a critical role in the design process from the very outset to the end stage of the product in use, all of the above-mentioned user-driven design approaches have developed ways and methods to help users to envision "use before actual use" and, in doing so, enable them to state their opinions and perspectives regarding the design. For example, scenario-based techniques have been introduced to bridge the gap between new design ideas and the implications that the realization of those ideas may hold in practice [29–31]. Ideally, a scenario should describe a new product in different (yet specific) usage situations and thus allow users to imagine the benefits of the proposed design through story-telling and description

[32–34]. Within PD, scenarios have been found to be well suited to supporting the interaction between designers and end-users. Scenarios have enabled the users to relate the design to their current activities and the designers to explain the opportunities of new technologies (see e.g. [33, 35]). Other commonly used methods and techniques to support envisioning and user involvement in design include product-related use cases and user personas. These techniques aim to model and simulate user interaction with the design solution and describe the background and lifestyle of the intended user [36]. Furthermore, different types of collaborative design interventions, like future workshops, have been introduced to provide end-users and designers with a possibility to engage in the process, to discuss problems and to create new concepts and a shared understanding about design solutions [37, 38]. Building mock-ups and prototyping enable end-users to experience potential design solutions, and iteratively alter them to better fit their needs and wishes [39, 40]. Prototypes have also been found to be useful for enhancing the communication and understanding of the design partners through grounding the discussions in concrete artifacts [41] as well as enhancing working relations through a shared ownership of the resulting designs [42].

Beyond these design-based (material-based: e.g. mock-ups and prototypes) practices, a number of tools and methods from outside design have been appropriated for design and user involvement. For example, ethnographic methods like field observation and studies have been widely adopted to deepen designers' emphatic understanding of users and the use context [43, 44]. Through a strong orientation towards the social organization of current practices, these methods are seen to inform system design to resonate with its use context [45, 46].

Despite a widespread interest in user needs and preferences, user involvement remains a methodological challenge, that is, the users tend to be tied with their experience of the present work and the immediate improvements of the tools. This is a major drawback particularly when the objects of design – that is to say, systems – are becoming more extensive and abstract, and hence more difficult to comprehend, even from the designers' perspective.

## 3. Functional modelling in developing user participation in complex system design

The central problem is that user involvement typically draws on methods that focus on particular targeted design solutions in particular situations of use. As these methods are practically inclined, users often find them concrete and easy to understand and discuss. However, as a consequence of concentrating on task- and situation-specific solutions, it is difficult to master the task-artifact cycle mentioned in the introduction and develop the work with long-term overall goals in mind. Moreover, as systems continue to increase in their scale and complexity, the power of traditional PD and collaborative design methods seems increasingly challenged. Adopting methods that enable abstracting generic features of the work system in question would support describing systems at different levels of abstraction in a way that would help both designers and users to comprehend the overall functioning of the system and see beyond the currently encountered individual task difficulties. The described limitation inherent in PD was also identified by Keinonen [47] who labelled such design as "immediate" and proposed complementing it by "remote" design with a more generic formative orientation. Such formative orientation is also emphasised by Kant [48] who provides further example of recent attempt to develop functional modelling in design of complex systems.

### 3.1 Functional modelling

Functional modelling may offer a possibility to comprehend the work system in more generic and conceptual terms, and view it from different levels of abstraction. Functional models are structured representations of the functions (purposes, activities, actions, processes, operations) within the modelled system or subject area [13, 49]. Functional modelling is used to produce a behavioural/operational model of a planned system. In essence, the resulting model describes how system functionalities have to cooperate in order to achieve the operational purpose of a system. A functional modelling approach supports building a means-ends hierarchy of a system, connecting upper-level goals and system functions to lower-level physical means, thereby at its best providing a comprehensive illustrative representation of the modelled entity. Moreover, functional modelling focuses on the functionalities that a future system should support without necessarily anchoring the structural means required for achieving those functions. The resulting models can facilitate the discovery of information needs and opportunities, as well as the identification of contextual restrictions and challenges (for a more in-depth discussion on functional modelling in design see e.g. [15, 50]).

There are several areas of complex systems design in which a functional modelling approach can be fruitfully exploited. For example, in process control, multilevel flow modelling (MFM) has earlier been introduced for the representation of the goals and functions of complex process plants. The resulting understanding of MFM has been used to develop diagnosis and planning support for process supervision and control [51]. Despite the clear advances that the MFM may offer in enhancing the designer's understanding of the functioning of the system, so far the modelling has not included a holistic behavioural description of the human actor as a part of the functional system. Neither has it been reported to have been used in a participatory manner with end-users. Similarly, Pirus, an experienced control room designer and also a former operator [52], has developed an innovative interface concept for a fitness process simulator. The concept exploits functional thinking in the construction of the interface, starting from the functional presentation of the plant structure and alarms. His justification as a former operator for the use of functional modelling as a base for representing the process and the plant was, however, the argument that process control operators naturally regard the process from a functional perspective. He claims that representing the process through functional abstractions fits the way that users (i.e. operators) comprehend the object of their activity: the power production process. Crilly et al. [53] suggest that conceptual models can be an effective instrument of thinking and a valuable tool in externalizing ideas to others.

Well-defined and structured functional models can help comprehend and logically work through the functionality of a proposed system in use, thereby serving as a kind of boundary object [54] in formative user interventions. Thus, functional thinking and models may also create a kind of common language that is characteristic to the idea of the third space facilitating participation [25] and that both the designer and the users are familiar with. The collaborative exploration of the functional model may lead to the clarification of existing design and user requirements or even the discovery of new ideas and design concepts. Furthermore, functional models may also encourage contributions from users that are difficult to obtain by other means (e.g. impressions and perceptions about the abstracted generic features of the work system).

## 3.2 A functional perspective on work and creative agency in core-task design

When designing new tools for professional use, a social and human factors perspective is central in pursuing tools of a good quality that appropriately serve the work at hand. In addition, the design of new tools should hold a holistic perspective and should take into account the capabilities of end-users to exploit the new tools. The above may be realized when work is not merely analysed in cognitive terms as actions accomplished by individuals interacting with certain features of the environment. An optional and more holistic possibility opens up when adopting "practice" as the key notion defining work. This possibility has also been proposed for HCI [55]. "Practices are stable forms of embodied acting that are appropriated in societal connections as meaningful for the community" [56]. Understanding practices assumes taking account of the broader field of practice in which they appear.

In specific, we understand practice as an activity to be defined in cultural historical activity theory and exploited (e.g. in the HCI tradition) [57]. Activity theory emphasizes the contextual understanding of work and therefore places the object of activity in a central role. The object of activity is the part of the environment that has become the focus of human attention and its motive. And thereby it is a part of the human-environment system [58]. Thus, the object of activity evidently affects how acting is structured.

We have strengthened the description of the object of an activity and developed an operationalization of it by introducing the concept of a core task [59, 60]. The core task defines the societal meaning of work and explicates, in functional terms, what is considered necessary for an appropriate fulfilment of work. The core task refers to "the generic developing content of the work and expresses itself as joint functions emerging from the meeting of the human organism's resources with the possibilities and constraints of the environment for reaching certain global objectives of work activity" [61]. Thus, one central contribution of ours is the generalization of the work activity beyond the individual work tasks, that is to say, the comprehension of the generic aims and possibilities provided in a certain work context, expressed as a core task [59]. An appropriate and developing work activity and tools cater for the potential inherent in the core task, in other words they provide support in achieving and maintaining the core task in all situation. In the design of complex systems, the core task may provide a comprehensive reference against that the activity can be viewed and analysed.

An important insight into the introduction of technologies in the context of complex work is that the artifacts (new designs) become professional tools through operational use in practice [62] – a phase in which only the real value of the design can be experienced and assessed. However, even in the early phases of development, it should be possible to gain indications of how promising or suitable the proposed new design is. Drawing on activity theoretician Engeström [63], we see that one key problem in complex system design is the methodical inefficiency of exploiting the user's professional knowledge and innovative potential in the developing their work and creation of new solutions. Too often the user's role is restricted to testing and evaluating predefined and long-matured solutions, instead of truly participating in shaping the solutions. In accordance with Engeström, we maintain that the creative role requires that beyond focusing on the specific design problem as the first stimulus that activates user participation, a second stimulus is required in the design activity. A second stimulus is brought in that comprises a tool for reflecting the problem and generating a solution. Different conceptual models are typical tools that serve as a second stimulus. These models do not only provide help for solving the initial design problem, they also create new generic knowledge about the phenomenon, become part of the user's expertise and empower them as creative agents in their work [61]. It seems that in the current approaches of PD certain types of models are used but typically without full awareness of their epistemic role in the design activity.

In design approach called core-task design (CTD), participatory design/ development process is enabled through and facilitated by three design functions namely: 1) Understand-to-generalize, 2) Foresee-the-promise and 3) Intervene-to-develop (see Figure 1) [64]. Generally, different type of models may facilitate the three design functions of CTD and serve as the second stimulus in supporting the design and development of work and tools.

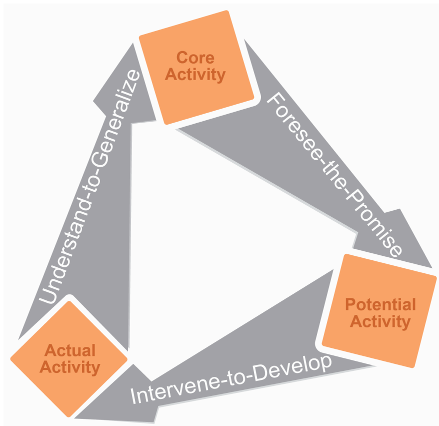


**Fig. 1.** The CTD approach. Three design functions indicated with transformative arrows [61].

The CTD design functions enable the transformation of the object of design through three states of reality in relation to the activity under consideration: 1) the actual activity, 2) the core activity and 3) the potential activity. The concrete actual activity may be abstracted to be the core activity (operationalized in the concept of core task[59]) in relation to which the future potential activity may be pursued in optional ways, and from which (finally, through formal intervention) the new actual activity may emerge. Hence, as a result, the CTD design functions aid the concerned activity to be viewed from three distinct perspectives. The design functions are not sequential by their nature (i.e. they do not represent a certain design process) but are instead all continuously present throughout the design. CTD approach aims at improving collaboration and participation in design by promoting and creating new means for communicate and conceptually comprehend the object of design. The change of perspective through conceptual models that aid users to proceed from the concrete to the abstract and from the present to the future is the creative power of CTD. In the CTD approach and its three design functions, functional models (e.g., core-task models and the so-called functional situation models [FSM] [65], or also other types of models) are in a central role when developing any work activity. Within CTD, functional models also represent a significant means to involve users and to facilitate their creative agency in design.

In the present paper, the particular focus is on the two of the CTD's design functions, that is to say, Understand-to-generalize and Foresee-the-promise design functions. The Understand-to-generalize function focus on the question of how to generalize from empirical enquiry about actual activity and answers this by analysing the generic elements of the present practice. The Foresee-the-promise function is dedicated to answering the question of how to see the promise of new solutions for future work. In answering this question, a particular emphasis is placed on the values and insights of professional users as regards new designs (i.e. concepts for future potential activity). There is a need for new methods that may further facilitate the creative agency of different design parties and could be use of in supporting the end-user's creative input and involvement in design. In CTD, different functional models may serve in this purpose.

# 4 Case Study: Foreseeing the potential of FI-enabled farming

To demonstrate the CTD approach and the use of functional models as a means of facilitating user involvement and participatory development within the CTD's three design functions, we turn to a design case that was carried out within the EU-funded SmartAgriFood project. In presenting the case, we exemplify how the use of functional models aided the development team in gaining user insight to support the system development.

All actors (e.g. consumers, retailers, producers and service providers) within the food chain are tightly intertwined and coupled together. In addition, the food chain is confronted with a number of global food chain challenges including food safety, environmental issues, and the ethical and sociocultural aspects of food production and consumption. Together, this creates a multitude of interdependencies between food chain actors, resources and products that needs to be acknowledged and understood in design. The structure of the food chain is particularly complex and one of a kind, which places significant demands on the design of technology to support the functioning of the system.

The EU technology community is engaged in an ongoing effort to develop the FI to serve socially important use sectors, for example healthcare and telecommunication, or agriculture and the food chain. The development of an open innovative infrastructure for smart services across these different sectors is covered by the FI (for more information about FI development within the EU, see [66]). The smartness inherent in FI-based systems or services mean that they are able to learn (adapt), to communicate the results to other devices and actors, and to develop their behaviour to best fit the situation [67]. Novel FI-based services are expected to be realized using generic enablers (GEs) – that is to say, reusable and commonly shared structures (e.g., data management, the Internet of Things) – offered by the FI-WARE core platform. The domain-specific enablers (DSEs) are identified as common to multiple applications within one specific and very limited area of usage: in this case, the food chain [66]. Hence, one of the more general goals of the SmartAgriFood project was to identify the DSEs that the food chain functions require for the development of the FI-WARE core platform.

In recent years, a number of food-related scandals have hit the news and shaken the trust of consumers in the quality of the food chain and the integrity of its actors. This has increased the demand for traceability. The FI is expected to increase food chain transparency as it provides effective tools for collaboration among actors and thereby enables the creation of a new kind of food chain awareness, that is to say, awareness among the different actors (namely the producers, industry, logistics, retail, consumers) about the global food chain challenges.

A particular application of the FI-enabled food chain activity reported here concerns food production and more specifically smart precision farming. Precision farming is an environmentally and economically effective modern form of farming that extensively exploits information technology in production planning and implementation [68]. We focused on a particular aspect of precision farming: the activity of pesticide spraying in arable farming. Spraying activity involves the complexity related to precision farming operation management, the dynamicity caused by the online and mobile information requirements, and environmental uncertainty (e.g. due to changing weather conditions), and it has implications particularly on food safety. Thus, in the context of arable farming, pesticide spraying demonstrates one of the most challenging set of requirements for FI technologies and provides an interesting case with which to explore how future technologies can be employed to assist people in their everyday work and to help them in maintaining a global food chain awareness. Smart spraying is used as an example throughout the case description to showcase functional model facilitated user involvement in CTD.

### 4.1 User involvement in the design of agricultural technology

Based on earlier experience of the design of farming technology [14], we knew that many attempts have been made to support management and operative work at farms, especially with regard to smart precision farming. However, despite several efforts, the results have not been very successful. The main obstacles were found to be the lack of understanding of the farmers' actual needs [69] and/or applying overly theory-oriented models to farming tasks [70]. The previous systems have also been found to be too difficult and time-consuming to use, and they have not been a good fit with farmers' work practices. Many systems have accordingly been difficult to integrate in practice [71, 72]. As a response to these lessons, Fountas et al. [70] proposed that information systems should integrate farmers' personal experience and their management goals into the data management solutions. Nurkka et al. [14] proposed that a usage-centred modelling approach should be used to achieve this aim. This approach draws on mediating between science-based knowledge of agricultural phenomena and practical knowledge of farming. In the present case, this usage-centred modelling approach was exploited as a starting point and developed further to present a FI-supported system to food chain actors. In particular, in modelling the future system, it was deemed important to convey and externalize the design ideas – that is to say, the innovations – in an illustrative way in order to engage the actors to participate in the design.

### 4.2 Method and materials

The detail with which users understand the properties and functionality of a technology strongly influences the actual use of that technology. The same also applies to their evaluations of the value of technology in their future work. In the present case, FI technologies and their possible applications are still much under development and therefore in their early stages of maturity – in other words they are in the concept phase. Thus, the users could not be provided with concrete products, not to mention functioning prototypes, with which to experience and engage with the use of a smart farming system. This section describes and elaborates on the role of functional models in CTD. In addition, a specific method, that is to say, a particular type of functional models called Tools-in-Use (TiU) models, were applied in the case study and will be introduced in this section. Following, a demonstration exemplifying how the TiU models are used as a main means to involve users within the CTD of future smart farming solutions.

### 4.2.1 The functional modelling of tools-in-use

With the aim of developing the use of functional models as a PD tool in the CTD's Foresee-the-promise design function, the Tools-in-Use (TiU) functional modelling approach was introduced. The TiU models serve two main aims: First, the TiU model makes the work activity explicit, contextually comprehended in the form of defined core tasks. As a particular type of functional models, the core-task models enable a generalization of the present work activity and create a basis for analysing the future value of technologies and for projecting potential concepts of new work. Second, in TiU modelling, the technical enablers are analysed and the major innovative functionalities of the proposed future system (i.e. the details of the design solution) are depicted, and the role of technology as mediating tools in work are made explicit. Thus, the TiU model includes familiar characteristics from both the end-user's world (i.e. the work activity represented in the form of a core task) and the designer's / technology developers' world (i.e. the description of the problem–solution space) but presents them alongside each other, being comprehended in a more generic/conceptual form. Similarly to the "third space of participatory design" idea of Muller and Druin [25], the TiU model may force the design parties – that is to say, the end-users and the designers – to move out from their accustomed "territories" and engage themselves in developing the new prospects together through negotiation, shared construction and collaborative discovery.

The benefit of the TiU models is that the participants may, step-by-step begin to Foresee-the-promise of the proposed solutions for future work. The content of the TiU model is collaboratively produced and different aspects of it are critically questioned and reflected in the design process. Through iterations the TiU model may little by little, be shaped into a vision of a meaningful and promising future. The participants of the design process are in control of the knowledge creation in the modelling process, thus the final outcome is something that all parties (i.e. the end-users and the designers) may relate to and refer to when solving the design problem.

In summary, the TiU modelling enables comprehending the functionality of the new solution for future work. It also facilitates examining the emerging solution as a joint human–technology system [73, 74], responsible for producing the targeted functionality. Moreover, constructing the models aids the users to see the potential of the proposed system in their work – that is to say, the affordances [58] – in the interplay between the actor and the artifacts (i.e. the tools to meet the demands of the work in question). The TiU model aims to present the work activity in relation to the proposed new design in a way that allows discussion about the value and the support it may produce if implemented.

In developing TiU models, we analyse, together with the end-users, the work activity and the technological enablers, and portray the values of the future system, its major innovative functionalities and the operation of the system in practice. The resulting model presents the higher-level functional goals (e.g. the functional task of human actors) in connection with the lower-level physical means (e.g. individual interface elements and design solutions).

The basic structure of the TiU model has three distinctive levels (Table 1). Each level captures a particular property of the joint human–technology system functioning. Constructing the TiU model is started with the uppermost level of the model – that is to say, the Value level – which describes the use values connected to the functioning of the system. This level includes, at least, a functional description of the work by making the core task explicit. The core tasks of a particular work are analysed according to a specific core-task analysis procedure [75]. That is, the core-task functions are analysed and comprehended based on enquiry (e.g., by means of interviews and observation of work) of the generic features (i.e., dynamism, complicity and uncertainty) of the work domain and the type of human resources (i.e., skill, knowledge, and collaboration and reflection) needed in the work. The Value level may also address, for example, the value-critical user experiences (UX) [76] and the business "value" propositions affecting the operation of the system. The intermediate level – that is to say, the HSI Concept level – represents the technology concept, which has two distinctive vantage points to be described: a functional requirement and a concept solution. When coming to the Concept level of constructing the TiU model the domain specific design expertise is often required. However, formulating the specific functional requirements and solutions is a dialogic thinking process and an iterative activity between the design parties. The focus is on describing the requirements and solutions from the perspective of their support on core tasks. The third and lowest level focuses on explicating the requirements and the content of the User interface (UI), which defines how well the functionalities of the system become affordable and realized. Also, in the description of the innovative features of the UI, both the requirements and the solution perspectives are comprehended and conceived from the usage point of view. The UI level is the most concrete level of the TiU model and thus often the most easily comprehendible for the designers and users. However, it would be important not to be too fixed at specific UI solutions at the beginning early on the design process because there are most likely many possible material means (i.e., UIs) to realize the support for the core task.

**Table 1.** The structure of the TiU model.

| | |
|---|---|
| **Value** | **The core task of the work:** The generalized control demands (dynamicity, complicity and uncertainty) of a particular work, as mastered by means of the skill, knowledge and collaborative resources of a human actor |
| | **Business propositions:** A value proposition is a promise of value to be delivered |
| **Concept** | **Concept requirements:** The concept level functional requirements indicate what kind of qualities the future system should provide for the users |
| | **Concept solution:** The concept solutions indicate the main ideas/construction of the elements that contribute to the delivery of the required function |
| **UI** | **UI requirement:** The UI requirements indicate how the elements of the interface should be organized in order the interface to be e.g. usable, effective, aesthetically appealing |
| | **UI solution:** The UI solutions indicate the main ideas/construction of the elements (the structural means) that realize the UI |

In the case study, through TiU modelling, the smart farming system is described in different levels of abstraction, starting from the farming work and its core-task functions, moving through to the level of particular design solutions to support the work activity. The developed models are enriched with the usage scenario descriptions and user-interface mock-ups. While the scenario descriptions and interface mock-ups attempt to make the specifics of the developed smart farming system explicit, the functional TiU models are needed to showcase and interconnect these singular operational situations and solutions within the wider context of farming activity and the food chain. Thus, the content of the scenarios and mock-ups directly draws from the TiU models and references may be done to the higher abstraction levels of the TiU models (Value and Concept level) while exploring the specific UI solutions through scenarios and mock-ups. The initial TiU models will be developed in close interaction with agricultural engineering experts participating in the project. Each model, however, is expected to get further elaborated and refined as regards food chain actor insights.

#### 4.2.2 Participatory design and participating food chain actors

The two first design functions, that is, the Understand-to-generalize and the Foresee-the-promise functions of CTD are emphasized in the present case study. Within the Understand-to-generalize function, the work activity is studied and modelled in order to understand its generic elements. In the Foresee-the-promise -function, the aim is to see the development potential and future solutions in the work. One underlying principle in CTD is the openness of the design process and learning, which means that while the participants create the solutions during the design interventions they become emotional owners of the solutions sketched together. In the CTD, the professional users and stakeholders of the target system are seen central actors and involved as active agents in the construction of the design solution. Their empirical knowledge but also the spontaneous resistance of chance that may exist among the relevant professionals may be extremely fruitful in relation to invention of new design solutions. The participation and proceeding of the present case study follows the CTD approach by firstly creating a commonly shared understanding of the smart farming activity and secondly enabling generation of future solutions and prospects that are found of value and promise.

A total of 82 food chain actors participated in constructing and evaluating the functionality and benefits of the proposed FI-based smart farming (see Table 2). Two kinds of user interventions were organized in order to gain insights about the value connected to the proposed concept: national discussion panels with participants from different food chain stakeholder groups and design workshops with domain experts (e.g. arable farming professionals, spraying contractors). For the national discussion panels, the participants were recruited through the large contact network of a project member, MTT Agrifood Research Finland[1]. The domain experts involved in the design workshops were known from prior cooperation to be active within the agricultural community and generally interested in applying the newest technologies in their work.

**Table 2.** Characterisation of the participating food chain actors

| Participants | Characterization |
|---|---|
| End-users<br>Domain experts | Farmers that are experts and have experience of arable farming or operate as spraying contractors. |
| Interest groups representatives | Representatives of some national interest groups such as agricultural organisations, retail and technology industries organisations. |
| Vendors of farming equipment/ systems | Company representatives/persons developing and selling farming equipment (e.g., tractors) or farm management systems/software. |
| Retailers | Representatives of some national retail dealer or a specified retail dealer (e.g., organic products or local food retailer). |
| IT experts<br>Software engineers | Company representatives/persons having a specific knowledge and expertise on internet technologies. |

Although the study was conducted in a continuous and iterative manner, for the purposes of this paper the description of the user involvement in the future smart farming system development process is divided into and presented in four distinct phases (Table 3).

Each phase involved a national discussion panel and a design workshop. The focus of the national discussion panels was to discuss the challenges of the food chain

[1] Nowadays known as Natural Resources Institute Finland (Luke)

in more general terms. In the design workshops, a small group of end-users were invited to participate in the design of the future system. The workshops provided a possibility to consider how future farming production, and especially pesticide spraying, could be developed, assuming the availability of FI technology. The design task was supported by the TiU models, the content of which was at the same time enriched by the farmers' experiences from the actual food production.

**Table 3.** User interventions through functional TiU models

| End-user interventions | | Human factors means & outputs (TiU modelling) | | System design |
|---|---|---|---|---|
| **Phase I: Shared construction of future smart farming**<br>• National discussion panel. Participants: 14 (8 end-users and 6 IT-experts)<br>• Design workshop. Participants: 2 farmers | ↓ | **FI supported food chain awareness** model (Figure 2)<br>**FI supported smart farming** model (Figure 3) | ↓ | Agricultural engineering and development |
| **Phase II: Collective discovery of smart spraying concept**<br>• National discussion panel. Participants: 11 (10 end-users and 1 IT-expert)<br>• Design workshop. Participants: 2 farmers | ↓ | **Smart spraying concept** model (Figure 4) | ↓ | |
| **Phase III: Service framework as model initiated innovation**<br>• National discussion panel. Participants: 23 (18 end-users and 5 IT-experts)<br>• Design workshop. Participants: 15 (8 farmers, 1 retail, 1 IT-expert, 3 researchers) | ↓ | **Smart farming service framework** (Figure 5) | ↓ | |
| **Phase IV: Shared agreement of the FI promise for future smart farming**<br>• National discussion panel 4. Participants: 15 (10 end-users and 5 IT-experts) | ↓ | An integrated model of **smart farming concept** including **service framework** and **smart spraying concept** (Figure 6) | ↓ | |
| Total number of involved end-users 82 | 1) End-users evaluation of the value of FI-supported smart farming and UX goals to guide the further development<br>2) DSEs of food chain aware smart farming for FI | | | |

The role of the human factors experts[2] was to introduce the methodology of functional modelling to be used by the participants in describing their view about the future of smart farming. Examples of the possible contents of the models were provided. During the user interventions the models could be readily edited if found necessary, however, the interventions were also audio-recorded allowing researchers return back to the specific points of discussions when further refining the TiU models.

Altogether six different conceptual and illustrative models were introduced in the process. The first model presented in Figure 2 was used for describing the main motivation of the project, the idea of a more aware food chain. The five other models that were constructed according to the functional TiU model described the FI-enabled smart farming system in different phases of its development

### 4.3 User interventions in the development of the smart farming system

**Phase I: The shared construction of future smart farming.** In the first phase of the case study, there were two main objectives. The objectives covered (1) how the farmers conceive the aims of their farming activity in relation to global food chain challenges and (2) what novel (innovation) possibilities they foresee the FI providing for arable farming. From a PD standpoint, Phase I introduced the challenge of how to initiate a shared construction of future smart farming and enable the participants' exposure to a creative agency. Functional models were utilized as pictorial representations in clarifying the future visions (i.e. the promise of the future

[2] The human factors experts in the project hold background in work psychology and industrial design.

system) in the discussions with panellists and domain experts. In particular, we introduced two models to aid the discussions: the first model was about FI-supported food chain awareness, in other words, about an overall model regarding decision-making structures within the food chain (Figure 2). The second model was constructed according to the TiU model and represented FI-supported smart farming, that is to say (FI) tools-in-(farming)use (Figure 3).

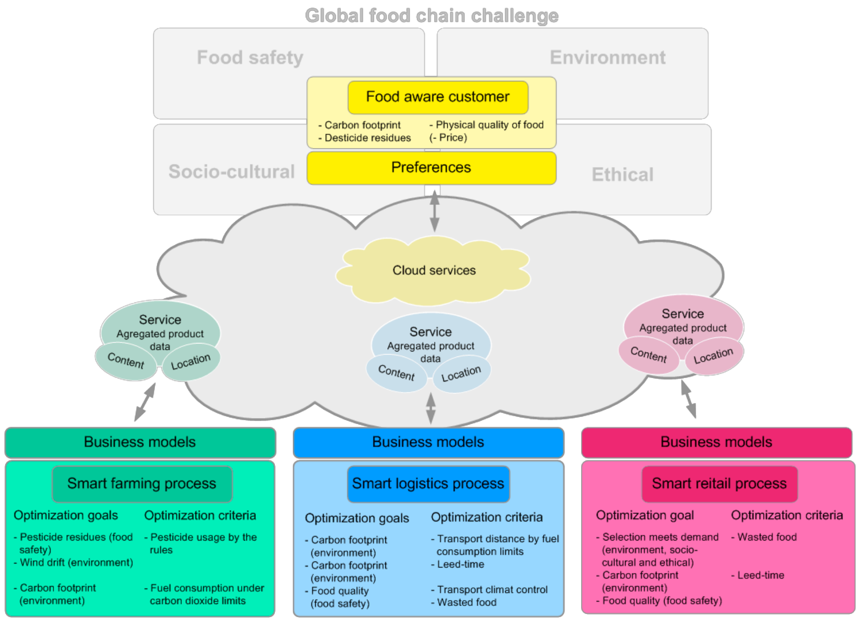


Fig. 2. The model of FI-supported food chain awareness

In the national discussion panel of Phase I, the FI-supported food chain awareness model prepared by the project representatives played a central role. The model was developed to illustrate the aims of the SmartArgiFood project, and it provided help to comprehend the variety of the aspects addressed in the project and their interconnections. The model demonstrated that all the actors and main activities of the food chain – that is to say farming, logistics, and retail (the food processing industry was wilfully not included in the SmartAgriFood project) – must take into account the global food chain challenges (food safety, environmental issues, and ethical and sociocultural aspects: see Figure 2). Not only the consumers but also the three food chain activities participate in the creation of an understanding of the global challenges and they must create awareness of the actual ways these challenges are met in food chain activities. As the model illustrates, consumers participate in the process by expressing their consumption preferences with reference to global food chain challenges. On the other hand, the three food chain processes portray their position with respect to the same global challenges via, firstly, making decisions concerning their business models within the food chain activity and, secondly, by considering global challenges in their decision making while accomplishing each of the three processes.

Establishing an illustrative summation of the project created a base – that is to say, created a shared problem framing – for further construction and collaboration around future food chain activity. Moreover, the model allowed the participants to recognize themselves in the context of the project and thus justify their involvement and expertise.

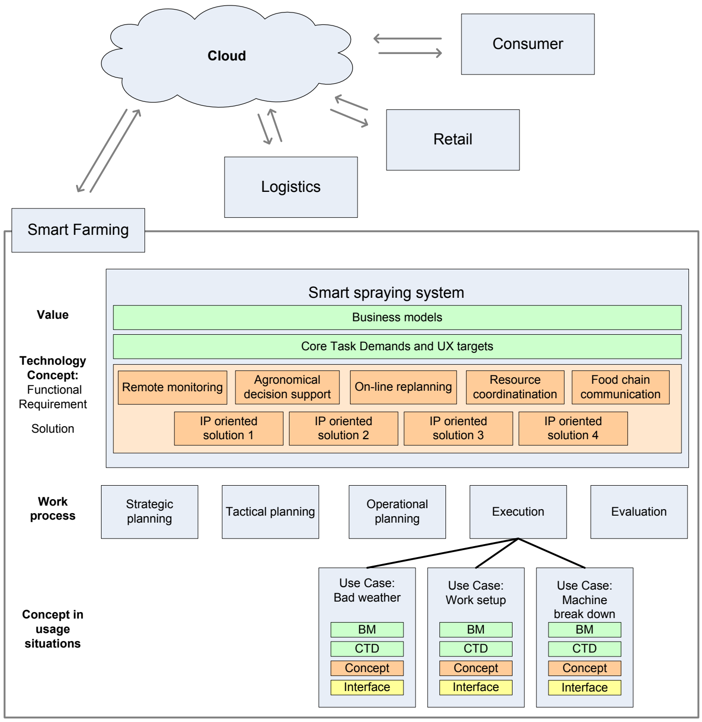


**Fig. 3.** The model of FI-supported smart farming

The second model utilized in Phase I was the functional TiU model of FI-supported smart farming (Figure 3). The first version of the model that functioned as an input for user intervention was prepared in close interaction with the agricultural engineering experts participating in the SmartAgriFood project. While the human factors introduced the general frame – in other words, the structure of functional TiU model and the analysis of core tasks – the agricultural engineers contributed by drafting the technical characteristics of the system into the FI-supported smart farming model. Following the three-level structure of TiU, in the upper part of the FI-supported smart farming model, the initial ideas for the FI-supported smart spraying system are externalized (in this phase the interface solution was still not described). The FI-supported smart farming model also presented the smart spraying system (described according to TiU) in relation to the overall farming work process (see the work process line in Figure 3) and the functioning of the system in particular spraying tasks/situations (see the concept in the usage situations line in Figure 3). Thus the FI-supported smart farming model comprehensively (from points of view of the core tasks, the overall work process and the situational demands) addressed the potential of smart farming concept and therefore was expected to facilitate further definition of the qualities of the smart spraying system. In essence, it also enabled realistically framing and focusing the design task at hand.

Consequently, the FI-supported smart farming model was used to facilitate the discussions in the first design workshop. In the workshop the model created an arena around which the different parties (the farmers as end-user representatives and the project representatives, namely the agricultural engineering experts) could gather and express their thoughts and points of view.

In addition, in constructing a common vision of the future system in use through the TiU model, scenario descriptions of relevant use cases exploiting the functionalities of the future system described in TiU were created in order to further concretize the spraying task (this being the particular farming activity in our focus). Three specific spraying situations were selected for scrutiny. These usage scenarios were (1) the work set up, (2) bad weather and (3) machine breakdown. Walking through these operational situations the farmers could express the specific task demands and knowledge required to carry out the spraying tasks. The technology developers, in turn, could respond to these demands by demonstrating the functionalities/qualities of the system with regards to the situational aid they may provide. For example, in collaboratively constructing the bad weather use case, the farmers noted that during the spraying operation they constantly monitor the weather conditions as the weather greatly affects the effectiveness of the spraying operation. In the case of a sudden change in the weather (e.g. sudden heavy wind causing the danger of pesticide drift and, as a consequence, the possible neglect of environmental and food safety in production) the farmers may need to adapt the original task plan online in order to better fit the emerging situation. In handling dynamic situations like, e.g., the bad weather scenario, FI-enabled smart farming holds the promise to giving greater support. The technology developers could now readily reflect on this and demonstrate their ideas about enhanced online mobile functionalities (such as re-planning the task) that the FI may afford.

The triggered discussions and the kind of dialogic contemplation of the TiU model enabled a design partnership where "every vote counts" to emerge and, consequently, created a contextually grounded foundation for further collaborative enhancement of the smart farming system.

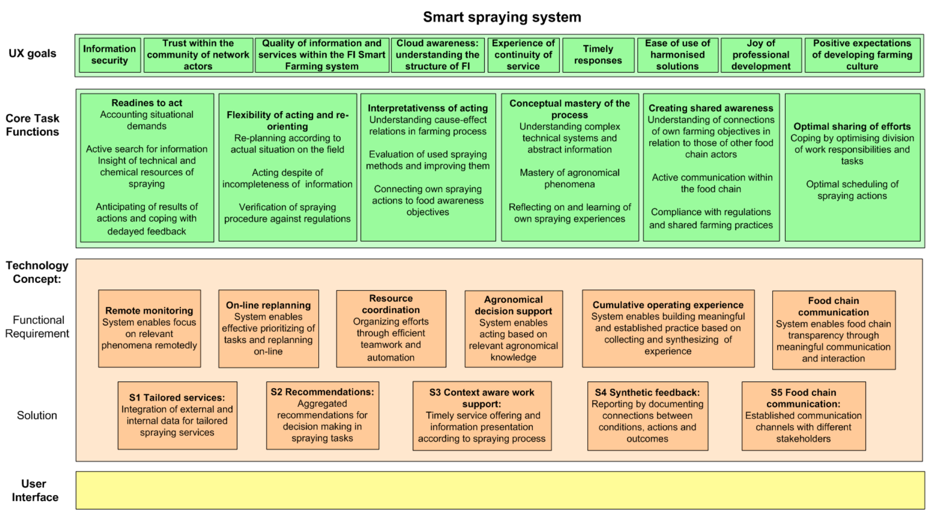


**Fig. 4.** The model of FI-supported smart spraying

**Phase II: The collective exploration of the smart spraying concept.** In Phase II, the main objective was to gain more detailed user feedback on the added value of the smart spraying concept. For this purpose, a second TiU model of the FI-supported smart spraying concept (Figure 4) was developed acknowledging the results (output) from Phase I and used as an input in order to facilitate both the second round of the national discussion panels and the design workshops.

The FI-supported smart spraying concept model was organized according to the basic three-level structure of the TiU model. The uppermost Value level (indicated with green colour) included an initial set of user experience (UX) goals and a description of work demands, that is, core-task functions. The nine UX goals resulted as an outcome from the discussions and evoked utterances in Phase I. With regard to the smart spraying concept, six major core-task functions were identified. These were derived on the basis of earlier core task definitions for precision farming [77] and further elaborated and concretized to address the particularities of spraying activity recognized in the earlier phase (Phase I).

In the middle part of the model, the technology-concept level, that is., innovative features, indicated with an orange colour, was described with regard to both the functional requirements and the proposed concept solutions. Six functional requirements and five concept solutions were identified. In describing the initial Concept level, the agricultural engineering experts played an essential role. Their involvement enabled deepening the descriptive power of the TiU model, especially in its lower (i.e. design solution) levels. Through the collective exploration with the food chain actors, the model was expected to become more refined and further developed.

In the national discussion panel organizes in Phase II, the smart spraying concept was addressed at a more general level. This was due to the fact that only very few of the panellists representing different food chain stakeholder groups had first-hand experience of spraying activity. Nevertheless, as the different aspects of the model were collectively explored, the discussions were still fruitful in eliciting concerns that farmers may have regarding the FI-supported smart spraying concept. In the panel, contributions were primarily made at the Value level of the FI-supported smart spraying model – put precisely, for values regarding experiencing the possibilities of the new technologies (i.e. UX goals). The panellists thought that the farmers would be interested in the possibility offered by the FI-supported smart spraying concept to get information about the needs and preferences of consumers. This direct link to customers was also expected to open up new business opportunities. Considering the consumers' preferences was seen as a key factor for the successful marketing of products. Furthermore, information security clearly seemed to be a major challenge for the acceptance and more extensive use of FI-based applications in agricultural production. The panellists saw that an equally significant challenge was to reach fair agreements concerning the pricing of the information offered to and exploited by FI-supported farming. The panellists' expectations seemed to be that the younger generation of farmers would be more ready to adopt the new ways of working and thinking about the profession. Furthermore, the panellists unanimously expressed that the metaphor of a "cloud" to describe the FI is too vague and does not provide a sufficient basis for judging the features of the concept. Therefore, later on more technical details including description of FI functions and architecture were provided for the discussion by the agricultural engineers in the project.

In the design workshop of the Phase II with the domain experts, detailed discussions could be held about the innovative features of the smart spraying concept and the core task support they may provide.

First, the six generic core-task functions (i.e., *readiness to act, flexibility of acting and re-orienting, interpretativeness of acting, conceptual mastery of the process, creating shared awareness* and *optimal sharing of efforts*) were dissected. The farmers were exposed to the core task definitions depicted in the value level of the TiU model.

It was asked if the farmers could relate both themselves and the demands of the spraying task to the generalization of the work activity (i.e. the core-task functions: see the core task level in Figure 4). Then the participants were encouraged to project the core content of the work onto the proposed concept for new FI-enabled spraying work, in other words the five identified concept solutions (S1: *tailoring services by combining internal and external data;* S2: *aggregated recommendations for online decision making;* S3: *the task-aware and timely presentation of information;* S4: *the context-aware reporting of decisions and tasks*; and *S5: networked communication*).

In practice, each concept solution was discussed and explored separately to allow the discovery of the support they may embody regarding the different core-task functions. In the discussion, the agricultural engineers emphasized the concept solutions from the design rationale perspective (i.e. how they assumed the individual solutions would contribute to the problem). Whereas the farmers in turn could critically reflect and evaluate the proposed solutions from the perspective of their everyday working practices. For example, in connection to the first *tailored services* concept solution (S1), the agricultural engineers aimed at providing more precise and personalized information by integrating external and internal data sources. The farmers immediately saw the potential of the solution, how it would allow them to easily connect local micro-level data (e.g. data from their private weather stations) to external data (e.g. data from the national meteorological institute) in order to create more accurate and suitable information to serve their specific needs (e.g. using the data for defining the contextually grounded setups of a spraying task). According to the farmers, at the moment, different farming equipment and machinery do not communicate with each other and to date only closed systems have been used. The participants experienced that the solution enabling the farmer being able to adapt her or his services to better suit her or his own purposes would be a big improvement and they could readily come up with many possible uses and situations to exploit the concept solution.

Another example about the collective discovery of concept solutions can be found from the *food chain communication* concept solution (S5) that aims to establish communication channels between the different actors in the food chain. The solution draws from the very heart of the SmartAgriFood project, that is to say, from the increase of food chain awareness. Nowadays, the information flow in the food chain is mainly one-way and not direct in the sense that the food producers (i.e. the farmers) have direct contact with the consumers. The farmers thought that genuine two-way communication within the food chain would add value to the farming business. Consumers could be provided with more detailed and meaningful information about the different products (e.g. the origin of the products or their production history). Furthermore, the farmers could make more precise production adjustments in line with market demand and feedback. Consumers are becoming more and more interested in how their food is produced; according to the farmers, traceability from "farm to fork" will be an important competitive edge in the future. By producing products that feature traceability information, farmers could also possible get higher profits from their products, as well as create more meaning for their own work.

In conclusion, the user interventions in Phase II provided confirmation of the advantages of the anticipated innovative features of the smart spraying system. Moreover, systematically working through the TiU model enabled a more informed discussion to take place, during which the perspectives of the different participants drove the concept forward.

### Phase III: A service framework as a model-initiated innovation.

In the third phase of the study, the project representatives based on the feedback from the previous phases refined the smart spraying concept and the respective TiU model. In the process of refining the smart spraying concept and in the development of the FI

architecture, the agricultural engineers in delivering the concept promise recognized a gap. In particular, even though the smart spraying concept was acknowledged to be promising by the participating farmers, it was also recognized to lack a more general framework (i.e. a technological enabler) through which the concept may have been employed effectively in everyday farming work. In that state the smart spraying concept would have been just another supplementary add-on among the farming equipment, therefore potentially resulting in additional tool management and interoperability issues, contrary to the original idea of providing ease of use and the tailoring of services. This observation led to an innovative leap, that is to say, an idea of a farming service framework that exploits the generic enablers of the FI to achieve the seamless integration of all kinds of farming related information technology services and equipment [78]. Thus, the service framework represents a kind of process control system in the farming context and may be utilized and tailored to fit not only the spraying activity but also other activities of arable farming. Moreover, the service framework provides the farmers with a communication channel to the relevant actor networks and would connect farming activity to the future information society at large.
The idea of smart farming service framework was introduced and demonstrated through a new TiU model (Figure 5), that was developed by the human factor specialists and project representatives as an input for the third round of national discussion panels and design workshops in the Phase III. In addition, UI mock-ups exemplifying specific features of the smart farming service framework TiU model were provided to further illustrate how the service framework and the spraying concept would be manifested in real-life usage situations.

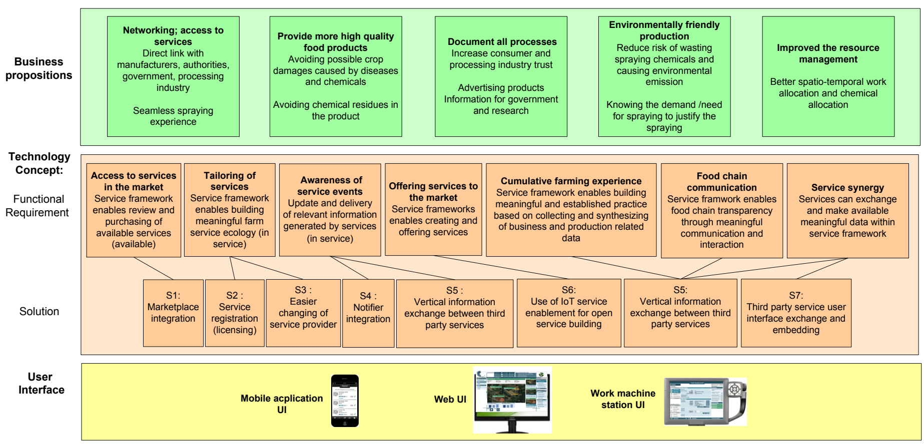


Fig. 5. The model of the smart farming service framework

Like the previous TiU models, the smart farming service framework was also described on three distinct levels (Figure 5). At the Value level (indicated with a green colour), the business propositions (i.e. the added value of the smart farming service framework for farming business) were identified and expressed. Altogether five business (value) propositions were defined: (VP1) *Networking (i.e. access to services);* (VP2) *Provide more high-quality food products;* (VP3) *Document all processes;* (VP4) *Environmentally friendly production;* and (VP5) *Improved resource management.* These business propositions embody the promise that the service framework holds for arable farming as a whole but they are also relevant from the spraying activity point of view. At the intermediate level (indicated with an orange colour) – the technology concept level – seven functional requirements and seven concept solutions for the smart farming service framework were identified. The proposed concept solutions were very technical in their nature and once again, the agricultural engineers had an important role in summarizing them in the TiU model.

Consequently, the presence of technical experts in the user interventions was crucial as they could readily comment in response to questions concerning technological details. In the third national discussion panel and in the design workshop the service framework model was discussed and collectively explored.

This time, interface mock-ups were also used for complementing and further illustrating the functioning of the framework in different operational situations. Thus, the proposed future system could now be comprehended fully through all the different levels of abstraction represented in the TiU model (i.e., work activity, concept and interface level). The agricultural engineers could easily refer to the reasoning behind the different aspects of the proposed system by logically working through and proceeding from the upper levels of abstraction to the lower ones. For example, from the business proposition of *Provide more high-quality food products (avoiding possible crop damage caused by diseases and chemicals while avoiding chemical residues in the food products) an Awareness of service events (the update and delivery of the relevant information generated by the services)* concept requirement may be derived and *a Notifier integration* solution suggested. Whereas, the interface mock-up of *Notifier functionality* allowed demonstrating how it may be manifested in a spraying situation in which the farmer receives an alarm from the *Plant disease pressure service* that he or she has taken into use. Thus, the TiU model was complemented with interface mock-ups (see the UI level in Figure 5) and scenario descriptions, allowing the participants to create a new kind of comprehensive relationship with the smart farming service framework, as well as allowing them to get their first situation-specific hands-on experience of the functioning of the system in the spraying task.

As a result of the third phase, the initial set of UX goals (also addressed in Phase I) for the development of the FI-supported smart farming system was further refined. Four main UX goals were defined (UX1: *Meaningful exchange of information;* UX2: *Experience of workflow;* UX3: *Sense of control;* and UX4: *Experience of developing farming work and culture*. From the design perspective, the UX goals [76] may be seen to express the wishes of the future potential users but also the worries and risks they may connect to the use of the system. The UX goal, *Meaningful exchange of information* (UX1), was connected to issues concerning the reliability and validity of information, smart information filtering mechanisms and information security. *Experience of workflow* goal (UX2) denotes that the system should be effective for its purpose, provide continuity of service and timely responses, as well as ensuring the ease of use of harmonized solutions. The third identified UX goal, *Sense of control* (UX3), is closely connected with so-called cloud awareness, (i.e. actors' understanding of the functioning and structure of FI-based services). It is fundamentally important for professionals to know their tools. Also, trust within the community of network actors is an important factor of the UX goal *Sense of control. The Experience of developing farming work and culture* UX goal (UX4) was seen to relate to the fair sharing of profit within the value chain and the joy of professional development.

### Phase IV: The shared agreement of the FI's promise for future smart farming.

In the fourth and final phase, the initial overview model of FI-supported smart farming (Figure 3) was completed according to the results of and elaborations in the user interventions in Phases I-III. The main addition concerned the inclusion of the smart farming service framework. It was found to be essential in realizing the initial smart spraying concept. As a consequence, the final model of smart farming includes two main innovations, that is to say, the generic service framework and the specific spraying concept solution, as depicted in Figure 6. In the previous phases, these two were presented through separate TiU models. For the final phase of the study, a summary model of the whole was created. The main aim of Phase IV was to get confirmation from the food chain actors that the development was heading in a favourable direction. Furthermore, Phase IV sought to verify that the defined core tasks and the UX goals created a solid foundation for developing a system that is in accordance with the needs of future farming and that the future food chain actors (i.e. the farmers) can adapt this system to their preferences and ways of working.

The summary model of FI-supported smart farming was utilized as an input in the last national discussion panel (Figure 6). In addition to the summary model, a questionnaire was compiled to gather conclusive evidence of the promise of FI-supported smart farming. The questionnaire consisted of six main questions, from which the first addressed the smart farming system in relation to the global food chain challenges and the following five addressed the anticipated benefits of the smart spraying concept. The five last questions concerning the concept characteristics were measured on a five-point Likert scale (with statements ranging from 1 = *not at all* to 5 = *very much*).

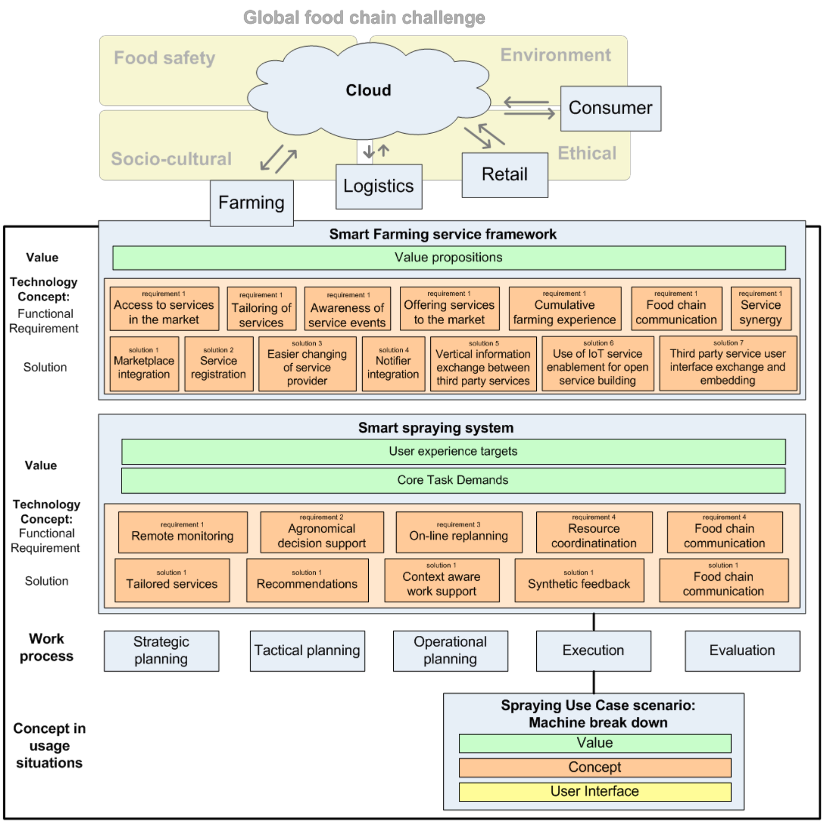


**Fig. 6.** The integrated model of the smart farming concept

In the final national panel, the food chain actors and the agricultural engineering representatives could once more get together and review the results of the collective efforts made to develop sustainable smart farming in the future. The session began with presentations summarizing the achievements of the SmartAgriFood project. Not only the food production of focused smart farming but also the other subprojects that concern logistics, and retail and consumer applications of the FI were introduced. After which the questionnaire described above was handed out for the panellists to fill in. The panel organizers, including the human factors specialists, collected the completed questionnaires and readily compiled a summary of the panellists' answers. As a final phase, the results of the questionnaire were shared and discussed together in the panel.

The results of the questionnaire demonstrate that the participants particularly connected FI-supported smart farming with a contribution to the food safety and environmental aspects of the food chain. Furthermore, they thought that the proposed smart farming solutions created possibilities for food chain actors to become more aware of the global food chain challenges. The results also indicated a strong agreement regarding the benefits that the smart farming system may provide for the optimization and development of farming activity. It was also foreseen that the proposed farming system would open up new business opportunities and improve the future prospects of arable farming at large.

### 4.4 Summary of the case study

Through the development of the TiU models in a farming-specific content, the possibilities of future arable farming work were presented to food chain actors. In the early discussions, especially in the first national discussion panel, the food chain actors expressed doubts and, in some cases, even pessimism regarding the possibilities of FI-supported farming. One reason for this was possibly that they did not fully understand the structure of the FI and cloud technologies. However, as the project evolved and more systematically defined TiU models, usage scenarios and UI mock-ups were collaboratively produced, the possibilities became tangible and the food chain actors' attitudes towards FI-enhanced farming became more positive. The actors needed to be familiarized with the proposed system so that they could form a picture of how the system might fit and support their current work practices or help develop them before they could realistically assess its value as a professional farming tool.

The participating food chain actors recognized the global food chain challenges, namely, food safety, and environmental and ethical issues, as well as the sociocultural preferences present that have a background influence on the everyday working activities of the farmers. In specific, the proposed farming system was seen to increase the effectiveness of work and reduce workload. However, perhaps more importantly, the system was seen to develop work, create new learnings and improve professional competences. These positive effects were linked to the improved integration and utilization of information, which would make it easier to comprehend the complexity inherent in agricultural practices and improve possibilities to interact with a network of farming professionals and wider communities connected to the food chain. In addition, a direct link to consumers was seen to further enhance business, and the safety and the quality of products. In addition, new development opportunities were revealed for the proposed farming system. The most pressing ones pertained to the efficient management and processing of information, compatibility between different systems, the reliability and security of information, and the automatic input and registration of information. Furthermore, it was recognized that it is necessary to provide education and training to farmers so that they will adopt the system. The third design function of CTD, that is to say, Intervene-to-develop that was not discussed much in the present paper would address this question of how to make the change in work happen.

## 5. Discussion

Functional models and active user involvement in complex system design lies at the heart of the research presented in this paper. The specific case context is the development of a smart farming system for which functional models formed a prime tool for user involvement. The scale and complexity of the food chain challenged conventional tools and methods for involving users and empowering their creative agency through PD. As a response, we applied usage-centred design and CTD as a methodological foundation and introduced a functional modelling approach, that is to say, TiU modelling. Through the TiU models, the ideas of technology developers were externalized and users aided in envisioning the functioning of the future system in their daily farming work.

### 5.1 The use of TiU for strengthening problem solving in design

Artifacts play roles for people, and people are motivated to use artifacts because of the new possibilities they provide for everyday living and working. However, uncovering the user needs, preferences and experiences that are critical for the design of new and often technologically advanced products and systems is not a simple task. As noted earlier in the paper, both the task and artifact coevolve [2]. Performing a specific activity sets requirements for the design of an artifact, but when implemented, the artifact changes the activity itself and reveals a new set of requirements. This only natural coevolution is something that is present at any work system but we also argue that by taking a practice as a new unit of analysis [64] the development of work systems may be sustainable and comprehensive in a way that the task-artifact cycle can be better mastered. We have suggested the CTD approach to be used in the analysis, development and design of work systems. By utilizing variety of functional modelling in CTD, particularly the use of TiU models, as a means of distancing the particular solutions and situations; we believe it is possible to promote the design of systems that are sustainable from the point of view of individual actors but also from more systemic and holistic points of view.

The CTD approach includes three main design functions: Understand-to-generalize, Foresee-the-promise and Intervene-to-develop. The present study in the paper mostly considers the two first ones: Understand-to-generalize and Foresee-the-promise. Within these functions, the work activity in question and its demands are comprehended and the promise of optional design solutions and development paths are considered. In early phases of design, it may not be possible to investigate the actual use of a new solution (UXs of functionalities provided by the system) as the design may still be in a too immature form to study the actual performance. Instead, feelings and professional intuition may provide a relevant vantage point from which to study the inclinations towards the forthcoming being and the future value embodied in the proposed new design solutions. Thus, the CTD relies heavily on the power of participatory processes and perspectives of professional users regarding developing their work.

In the present paper we have used functional modelling, especially TiU models, to enable food chain actors to imagine the potential of the FI to develop the food chain activities and to communicate optional future systems to them. In particular, a general TiU model structure with farming-case specific content was established to serve the purposes of the SmartAgriFood project. The TiU models allowed a different perspective to the farming work from the traditional task performance-based view. The TiU models constructed for the user interaction in the project were aimed to provide the participants with a conceptual tool that would allow them to better approach the problems and grasp the proposed future concepts.

Whit the help of TiU models, the developing design solutions become captured in an illustrative form and a gradually deepening understanding of the possible strengths and weaknesses of the design solution can be achieved. Starting the construction of TiU model (i.e., the Value level) for analysing the core-task functions of the activity at hand aims at creating an understanding of the generic demands of that specific work, content that needs to be maintained in all situations. Thus, the conceptual logic of constructing the TiU is to start from the abstract/generic knowledge of work activity and then move towards a more concrete description of solutions (i.e., Concept and UI levels) that may support and develop the activity. The procedure and structure of TiU guarantees that the development of new design solutions consider and is contextually grounded on the real requirements of the work activity. Arguably, the developed case-specific TiU models provided users with a conception about the overall functioning of the future system as well as detailed descriptions of its application in specific usage situations. Users' having profound knowledge about their work may be able to understand something about the potential effects of the proposed design solutions that is not evident for the other design partners. In the study, when collaboratively working through the TiU models, the models aided the participating food chain actors in considering how the proposed system would affect their individual work practices and, by extension, the functioning of the whole food chain. One indication of participants' improved comprehension of the possibilities of future farming became evident by the fact that they felt comfortable to state their opinions even though not always holding a core competence for the question at hand. Thus, the TiU models' Value level provided an understandable description of the demands of the work activity. Moreover, the participants, and especially the domain experts holding specific expertise on the topic, could reflect the proposed design solutions upon the faced challenges and problems of their daily work and come up with improvements or even very new FI-based solutions and functionalities relevant to them. For this reason, we claim that the TiU models initiated a thinking process and facilitated reflection and generation of new insights, indicating intensive engagement in the design task and problem solving.

When looking from the system-engineering point of view, the used TiU models aided the agricultural engineers to make connections from the specifics of the FI architecture (the technology) to the expected farming and business functions and the ultimate objective of improved food chain awareness. Thus, the models enabled exploring the design space from a broader perspective but also from the point of view of the users and the usage of the proposed solutions. Enabling an augmented envisioning ability of designers that in the end may arguably have made the innovation of the service framework in the project possible.

Both the food chain actors (e.g., farmers) and the design engineers in their daily work handle very concrete problems and issues such as sow the field or work on some technical construction, however, the TiU model helped them to view also their own profession on different levels of abstraction (i.e., Value and Concept level). For example, in assisting to build the initial TiU models the engineers were guided to first describe their technical solutions from conceptual point of view and judge how they aim to address each of the core-task functions to form a kind of concept of operations [79] for smart farming system. Thus, from the system, a high-level description of how the elements of the system and its environment communicate and collaborate in order to achieve the stated goals is first emphasised. It may be that this is not always straightforward for practically oriented designers and several iterations are needed in order to summarize and define the concept clearly. However, we believe that both the engineers and the users can take this conceptual step up and handle the object of design in terms that are more abstract, and the TiU model aid them in this by making the work activity and the technology concept explicit.

In learning from our experiences, some practical issues regarding the development and utilization of TiU modelling should be mentioned. As with most qualitative research tools, constructing models requires a lot of preparatory work in terms of data collection and analysis in order to clarify the main elements of the TiU models. To understand the work and to define the core-task functions of the specific work activity at hand, one must contextually analyse the work activity, that is to say, carry out core-task analysis [60] and enquire into the practitioners' world. Moreover, the development of the models often requires cooperation between different disciplines; for example, technical knowledge of the FI was essential in the present study and in describing the specifics of proposed smart farming solutions. However, all these efforts may yield benefits in the form of more structured, context-focused and work practice-oriented discussion between the different design partners and perspectives. As in the TiU model, the work activity may be comprehended together with the future solution in condensed and illustrative form; one apparent advantage of TiU model is that it may easily give an immediate overall impression of the future system presented in one singular illustration. This quality is the one that most often positively surprise the design engineers, that is to say, the main ideas of their design solution may be made comprehensible in one sheet of paper without needing to go through extensive design documentation. However, the TiU model enables also when logically work through to study the functionalities of a proposed solution almost in any detail. As a result, the outcome of the user interventions, that is, the exploration of TiU models regarding future smart farming, was not only restricted to the value seen in the details of the design concept but more general knowledge was also produced that may guide the design of further parts of the food chain system.

## 5.2 The PD process and creative agency

Solving any problem can make use of a multitude of perspectives and the same applies to the design of any products, services or systems. Particularly, in the design of complex work systems, knowledge from many technical disciplines is required, not forgetting the important role that the professional skills and knowledge of end-users may play. This is why, in the design of complex sociotechnical systems, participatory processes that empower the end-user and develop creative agency among them should be pursued.

We have used TiU modelling as a methodological means of facilitating user participation in the design of FI-supported future farming. The TiU models constructed for the project included three descriptive levels: 1) the Value level, 2) the Technology Concept level, and 3) the UI level. At the Value level, the work activity at hand is functionally comprehended, whereas at the technology concept and UI levels the problem–solution space for the particular design task is framed. Thus, the TiU models include recognizable elements from the worlds of both the users (i.e. the core tasks of farming work) and the technology developers (i.e. the specification of the technology concept). Therefore, there is always an element in the TiU model, which design partners may feel familiar with and relate to themselves. Consequently, having ownership of part of the content of the TiU model and not feeling that one is totally coming from outside may assist design partners in approaching the design task from their own perspective and standpoint. While at the same time, it may help the partners to construct a shared new point of view and common language through which to discuss the future system. As a result, the kind of third space (not owned by any design partner particularly but instead shared by all equally) referred by Muller and Druin [25] may be created that may be fruitful grounds for new insights and the collaborative development of systems. TiU models may also be seen as a new kind of boundary object that may facilitate more integrated and the multidisciplinary development of complex systems. Within the two specific forms of user interventions – namely national discussion panels and design workshops – participants with a variety of backgrounds could come together and be introduced to the challenges and issues displayed by the future food chain. At the beginning of the series of user interventions in the SmartAgriFood project the TiU models functioned as an introduction to the project at hand and aided the participating food chain actors to position themselves in relation to the themes and activities of the food chain under consideration. Moreover, the models helped in diagnosing the current state of the food chain and establishing a shared framing of the design problem. During the development, the TiU models functioned as a shared frame of reference when collaboratively working with the agricultural engineers and the food chain actors. Thus, through collective exploration of the models, an iterative exchange of thoughts and ideas between the development of future technologies (i.e. the FI) and the practical farming work could take place. Nevertheless, even clearly being a new kind of boundary object in complex system design, we feel that mere TiU models based representations are not always sufficient for comprehending the complex object of design. For example, FI in the project was needed to be described with also other means (e.g., architecture drawings) than TiU, however, exploring the TiU models revealed this ambiguity felt by the users.

The role of TiU models as a shared reference was especially evident in the interaction with the food chain actors and particularly with the domain experts as they could be invoked to discuss the details of the proposed system with very subtle instigations. The more general CTD approach and especially the introduced TiU models were a central conceptual tool and a language, enabling the creative agency in the design by providing a third space type of new view to the object of design. Moreover, the TiU models aided the interdisciplinary team of specialists in resolving complex lines of thought and forming a general concept for the emerging system. Thus, in the project, the TiU models served both as PD tools enabling user involvement and creative agency, and as reflective design tools enabling technology developers to externalize their design work and problem-solving processes. The advantage of TiU models is that their use is not restricted to any specific type of user interventions. In the present study, they were utilized in the panel discussions with dozens of people as well as in the design workshops with one or two users. In the future studies of TiU model, also other type of user interventions (e.g., focus groups or operating experience reviews) could be explored.

As design is an iterative activity by its nature, it may also be expected that the TiU models develop and mature over time. The experienced maturation of the TiU models may also encourage users to provide new feedback and input. For example, many of the participants in the national discussion panels participated more than once and followed the project from the beginning to its end. A rewarding element of the participation that encouraged more engaged involvement in the project was that the food chain actors could see that the refined models incorporated the feedback they had provided in earlier panel sessions. This aspect most likely should be considered carefully when planning user interventions, especially if the aim is to build a longer-term engagement with the users. The gradual documentation of the development process also captures important pieces of background information and the rationale behind the different design decisions improving monitoring of the design process.

## 6. Concluding remarks

In this paper, we have addressed user involvement in complex system design. In specific we have reported on the use of functional models for collaborative discovery of the operational qualities of a new system and as a descriptive tool to facilitate active user involvement in design projects. The context for our study was the FI and the design of a food chain application, namely a food production-focused smart farming system. A variety of food chain actors participated in the design through planned user interventions. Functional modelling, particularly using TiU models, served as a methodological means for developing the future system with the users.

In conclusion, the study of the participatory and functional model facilitated design of a future food chain system, produced interesting results that help in understanding some aspects and challenges of the socially important sector of food chain activity. More specifically it addressed the question of food production and the task of pesticide spraying, and revealed the contextually grounded demands of the work and the expectations (both operational and experiential) that the food chain actors, and especially the farmers, have for the design of professional farming tools. It also involved the food chain actors and helped them to comprehend the transformation that the food chain and society at large are undergoing because of the digitalization and the possibilities that the FI may provide.

The study reported in this paper makes two distinct contributions. First, it provides an example of how a variety of user and stakeholder groups can gain creative agency through CTD and the collaborative exploration of functional TiU models and thus express their informed opinions about the design of a future system. It highlights the TiU modelling and the use of functional models as a means of user involvement, thereby extending the current repertoires of methods for the PD of complex system. Second, the functional modelling and the pictorial models developed in this case study give guidelines and inspiration for how to tackle the problem of describing something that as yet only exists as the visions of technology developers. In particular, users' insights and evaluation of the value of the proposed system helped the technology developers further their initial ideas towards a more comprehensive concept. Finally, we hope that the paper contributes to bridging the gap between future visions and the realities of work, and allows professionals' skills and knowledge to be the creative power in the design of complex systems.

**Acknowledgments.** We would like to acknowledge all the members of the SmartAgriFood project (funded by the Future Internet Public Private Partnership Programme of the 7th Framework Programme of the European Commission) and in particular, those that participated in realizing the Smart farming work package. We are especially grateful to Liisa Pesonen for her comments in the process of preparing the manuscript. We wish to thank also the end-user representatives that expressed and shared their valuable thoughts about the farming system development and the challenges of the future food chain activity.

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