A Methodology for Process Modelling in Living Labs to Foster Agricultural Digitalisation

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***Abstract*—Agricultural digitalisation presents socio-economic and technical challenges with double-edged effects, generating potential winners and losers. To minimise the risk of undesired consequences, it is important to early evaluate its impacts by adopting an interdisciplinary approach. This paper presents a methodology for conducting socio-technical process modelling in living labs, i.e., co-design environments constituted around an emerging problem, in agricultural areas. The methodology foresees the development of diagrams based on formal notations from software engineering and a step-by-step procedure for the co-creation of the models. To consolidate the methodology, we apply it to the case study of *Pecorino Toscano*, a living lab presently evaluating different technological solutions for livestock and cheese production. This preliminary evaluation reveals that the adopted approach is sufficiently flexible and effective for information exchange, and can be successfully applied in a co-design environment.**

***Index Terms*—process modelling, co-design, agricultural digitalisation, living labs, digital agriculture**

I. Introduction

The adoption of digital technologies in agriculture triggers a complex process of socio-economic and technical change called digitalisation that radically transforms the context in which human activities are performed [1]. Digitalisation can have double-edged effects, with winners and losers [2], and, to prevent undesired consequences, it is important to evaluate the impacts of the transformation beforehand from multiple perspectives. Furthermore, an interdisciplinary approach has to be adopted for shifting from a technology-driven paradigm in favour of a sustainable one. For this reason, research shall prioritise co-design environments in which different solutions based on digital technologies can be designed, developed, tested, and evaluated with the stakeholders, in order to reach more inclusive, sustainable, and human-centered solutions [16]. In the framework of the European research project "Digitisation: Economic and Social Impacts in Rural Areas" (DESIRA) [3] an inventory of digital tools adopted in agriculture, forestry, and rural areas was created starting from an online survey administered to stakeholders active in these domains. The inventory provides a classification of the digital tools, ranging from web-based systems for data collection and analysis, to robotics and autonomous solutions. Beyond the focus on emerging digital solutions, related application scenarios were analysed. This brought to the definition of different contexts of the use of digital technologies, which were grouped per topic. For example, in the agricultural domain different tools are adopted in crops for fertilisation, harvesting and pest control; or in livestock for feeding, monitoring and reproduction[1]. The analysis of several application scenarios allowed the detection of three maturity levels that a technology may have: 1) proof of concepts; 2) under testing; 3) already in the market. This contributes to the evidence that different factors, drivers and barriers may influence the adoption of digital technologies [2]. Furthermore, the concept of socio-cyber-physical system (SCPS) emerged. A SCPS is intended as a system integrating physical components, computational and communication elements and the social dimension. This framework can be applied for the analysis of real agricultural contexts affected by the process of digitalisation [1].

Following the outcomes of [2] [3] [4], we focus on evaluating the impacts of digitalisation in the context of an ongoing research carried out in Horizon Europe project "Maximising the CO-benefits of agricultural Digitalisation through conducive digital ECoSystems" (CODECS) [5]. This can be done through qualitative and quantitative assessment of the transformation of the business processes conducted in real agricultural contexts. We perform our research in living labs (LLs), i.e. networks of farmers, knowledge intermediaries, stakeholders, policy makers constituted around an emerging problem [7]. Thus, our aim is to evaluate process re-engineering making a comparison of the process *before* the introduction of digital technologies (*process as-is*) and *after* the adoption of digital technologies (*process to-be*). This can provide clear information about actors, resources, activities added or removed from the process and allows even deeper evaluations. A central activity to enable these evaluations, is

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[1]The inventory of digital technologies is available at: https://desira2020.agr.unipi.it/wp-content/uploads/2020/11/D1.3-Taxonomy-inventory-Digital-Game-Changers.pdf, last accessed 8 July 2023

the farm socio-technical process modelling in LLs. Starting from a focal action situation, i.e. a situation where components of a socio-ecological agricultural system interact to provide an outcome, our objective is to identify the process transformed by the introduction of digital technology and provide a comprehensive representation of this transformation which would be understandable to all stakeholders involved in the LL and useful for further analysis, e.g. cost-benefit analysis. A clear representation of the process can also support the assessment of readiness at the farm level, which is intended as the measure of the farmers' level of adoption and effective use of digital technologies in their agricultural practices. In a previous study [6] we introduced a methodology to carry out process modelling based on the development of easy-to-read graphical representations leveraging formal notations from software engineering, i.e. model-driven requirements engineering techniques (MoDRE). Process modelling aims to resolve issues arising in information exchange brought by transdisciplinary research and direct involvement of LLs. In fact, for the generation of such representations a collective effort is required, as the models are the outcome of the knowledge of domain experts, such as farmers and advisors; researchers in different fields, e.g. economics, sociology, ecology, engineering; and technical expertise on the formal notations needed to produce the models. Supporting information exchange between all stakeholders involved in the development of such models is crucial and a procedure balancing the need for autonomy of LL participants and structured knowledge elicitation to create the models is currently under development. The methodology will be based on a template and a guided procedure for LL coordinators will be refined and evaluated within 20 European LLs in CODECS. The aim of this contribution is to consolidate the process modelling methodology. Therefore, we selected a LL from CODECS to carry out a second case study. In the following, we present the co-design activities carried out so far in the framework of CODECS project in the Italian LL Pecorino Toscano and the progress occurred to the methodology under-development.

II. Methodology

The research is carried out in living labs as real agricultural contexts. LLs are collaborative innovation environments involving end-users, enterprises, public bodies and universities, in the evaluation and implementation of original solutions, based on a systematic approach of co-creation and co-development. LLs also act as intermediaries between citizens, research organisations and companies to co-create new services, common values and social infrastructures focused on common needs. The concept of LL was introduced to describe a user-centred research methodology capable of detecting, prototyping, validating and refining complex solutions in multiple and changing contexts [7]. The term *living* refers to the fact that LLs focus on evaluating solutions in a real-life environment rather than in a controlled laboratory environment, and seek to mimic the actual context in which the solutions will be used and evaluated. LL is a dynamic multi-stakeholder network, which aims to stimulate and manage innovation led by users in real contexts, or to stimulate the interaction between technological and socio-economic forces [8]. The research in such user-oriented systems can be performed in a limited geographical context and in a defined period of time, with a view to the application of the results on a large scale.

The focal actual situation (FAS) is a situation where components of a socio-ecological system interact to mobilise digital technologies in order to provide an intended outcome, change, or state. In order to better understand and describe the functioning of the FAS, the LL will be involved in an experience of co-design of the process of interaction and provision of the intended outcome, change or state with and without the digital technology identified.

III. Process modelling

Process modelling is carried out to understand how current processes are re-engineered after the introduction of digital technologies. The transformation is emphasized by qualitatively highlighting the differences in the process *as-is* (before) and in the process *to-be* (after). The activity is based on the application of Model-driven requirements engineering techniques (MoDRE) [9] which leverage diagrammatic notations from the field of software engineering as a means for information exchange between stakeholders with different backgrounds and expertise. To ensure completeness of the representation, a set of formal languages has been so far identified and the following diagrams will be developed for each LL:

- the *structure diagram* in UML [10] will provide an overview of the actors, tools and infrastructures involved in the process, the main activities and the relationships among them;
- the *goal diagram* in i* will model the goals of the process focusing on the intentional, social and strategic dimensions [11];
- the *process diagrams* in BPMN [12] will represent the detailed flow of the process and will allow comparisons between the overall process before (as-is) and after (to-be) the introduction of the digital technology [13].

In order to assess the modelling methodology, a pilot study on a smart irrigation system adopted on a pear orchard by Illuminati Frutta [2], a fruit farm in Tuscany, was analysed and the diagrams mentioned above were drawn. The pilot study, along with the developed diagrams, are presented in [6]. The adoption of a precise irrigation system, which is based on a digital solution composed of a wireless sensor network (WSN) and a decision support system (DSS), has promising potential in terms of economic, productive and environmental benefits. In order to study the impact of digitalisation, such representations can be useful to multiple stakeholders for assessment at different levels, for example for having an immediate and clear view of the process transformation in terms of actors and activities, or for providing specific data for advanced assessment, such as cost-benefit analysis.

[2] http://www.illuminatifrutta.it, last visited 8 July 2023

The procedure adopted to define the models in the pilot study is as follows:

- A team of agronomists and economists from the University of Pisa and computer scientists from CNR visited the farm and dedicated half a day to interacting with a group of ten people who consisted of farmers, agronomists and the owner of the farm.
- The agronomists from the University of Pisa wrote a report describing the system structure and the automated process currently under development, especially describing the change with respect to a manual process.
- Based on the document, the team from CNR created the diagrams. These were revised with experts in i*, class diagrams and BPMN, and this led to 11 changes to better comply with the grammar of the formal notations
- The diagrams were used to further clarify certain aspects of the system in a 2-hours meeting with the agronomists. This led to 2 substantial changes in the diagrams, (new components and relationships in the UML), and the meeting showed that the agronomists clearly understood the notations and were able to provide feedback.

The current research challenge is to set up a methodology to carry out process modelling in LLs based on a guided procedure to be managed by LL coordinators. The procedure will be based on the co-creation of the models by LLs and software engineers. The methodology will be adopted and evaluated in 20 LLs in CODECS as part of the second year activities. LLs focus on different technological solutions, e.g. proximal and remote sensing, machine learning/AI, decision support systems, robotics and automation, which are applied to different contexts, e.g. diseases and pest management, soil and nutrients management, animal welfare, communication, marketing and education.

As the same methodology will be applied to 20 LLs, it should be flexible in order to adapt to different LLs' needs. Models developed should represent different technological solutions, different readiness of the adopted digital solutions and different set up of the LL.

IV. The case study of Pecorino Toscano

Pecorino Toscano is a LL based in Manciano, Tuscany and it is focused on the activity of sheep breeding and pecorino cheese production. The LL is built around the activity of the "Caseificio di Manciano" which is collecting sheep milk from several local farmers and processing it to produce pecorino cheese. Part of this cheese is certified P.D.O. The LL involves the farmers, the processors, the "Consorzio tutela Pecorino Toscano D.O.P.", and the advisors working with the farmers of the processing plant. Local administration such as the municipality of Manciano and the Tuscany Regional Administration are also participating in some LL activities. In 2023 the Caseificio di Manciano is becoming one of the Tuscany Region Community of Practice on precision agriculture.

Thanks to farms' investments and to the participation to previous research programmes at regional and national level which provided funding for technological development, a series of technologies aimed at supporting the work at various levels have been developed so far, or are currently under development or evaluation: a prototype of a farm management system with an app to monitor animals' health status and food ratio optimisation; smart collars to protect animals against wolves; a blockchain-based system for farm-to-fork traceability; a technology that works near the infrared spectrum for the evaluation of feed (hay and concentrate) directly on farm. Even if the participation of the LLs in CODECS is expected starting from the second year, co-design activities in Pecorino Toscano started beforehand; this resulted in supporting the methodologies for setting up both FAS and process modelling. Three introductory meetings were held so far with the aim to establish the identity of the LL and have a common view of the problem to address in FAS. A first meeting was held in Manciano at the headquarters of the cooperative in November 2022. The aim of this meeting was to set up the LL by introducing the role of each participant. A visit to a demo farm which is introducing different technological solutions and an interview to the farmer was also part of the day. A second meeting was organised in February 2023 in the framework of the community of practices of the Tuscany region. A third operative meeting was organised in May 2023 at the Department of Agricultural Economics at the University of Pisa; after this meeting it was time to identify priorities among various alternatives proposed by the collaborative team.

After the three meetings it was possible to have a clear view of the actors involved, their role, available resources, the main activities carried out in livestock and cheese production and the goals within the overall process. Special attention was devoted to understanding needs and common problems which threaten the current process, and to identifying the technological solutions adopted in order to solve these challenges. The main goals which the LL aims to address with the support of technological solutions are:

- automate updates to the national animal registry;
- monitor animals' health and reproduction for milk traceability and sheep selection;
- monitor animals' productivity;
- management of the production chain and data interoperability;
- protection of flocks from predators.

The diagram in Fig. 1 was developed by the University of Pisa and represents the output of the co-design activity carried out so far. The same diagram is also a source of input data for the creation of the formal diagrams to be developed in process modelling, i.e. structure, goal and process diagram. A first version of the structure diagram in UML was developed starting from this input and is represented in Fig. 2. The diagram contains actors, activities and relations as identified in the diagram in Fig. 1 along with a more specific representation of the technological components, i.e. a Farm Information Management System (FMIS) which automates the recording and storage of farm data both through sensors and user input, monitors and analyses farm activities, and

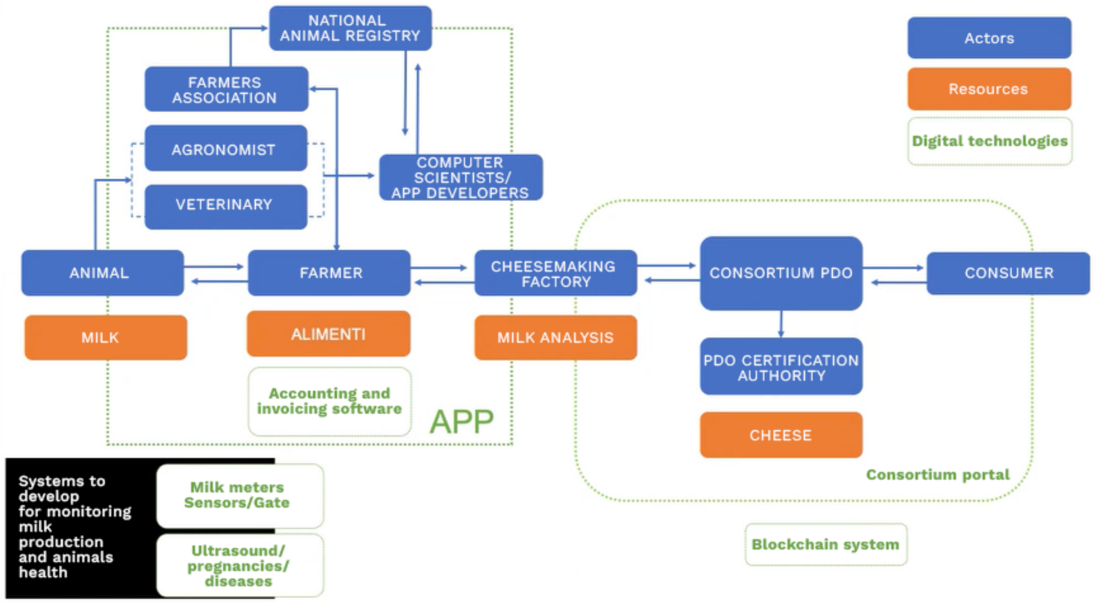

Fig. 1. Outcome diagram from the co-design activity devoted to the definition of the focal action situation

provides data access to several actors. This formalisation aims to support LL participants in better understanding the relations of the technology with actors and resources in the system, and at the same time it supports technology providers in future implementation. This is to be intended as a first version to be refined in further iterations with the LL. During an online meeting in June 2023 the diagram was presented to the actors of the LL and validated. To complete the other diagrams, i.e. process and goal, further data are needed. In fact, the diagram developed by the University of Pisa mentions different technologies which are being evaluated by the LL, but does not deepen a single technological solution. This can be intended as a side effect of the co-design activity being carried out. In fact, as the co-design progressed, it has emerged a tension between the dynamic nature of the LL, which is continuously changing its assets evaluating different solutions brought by the different perspectives of the participants, and the need to focus on a technological solution to be evaluated as the key process to solve an isolated problem. Starting from the FAS, the process transformed by the digital technology to be modelled will be extracted and targeted interviews will be carried out with key informants. This will contribute to understand the process in detail and how the technological solution helps to fulfill specific goals of different stakeholders in the value chain. The interviews can be carried out by living lab coordinators in the context of collective activities following guidelines provided by the authors. The guidelines will contain specific questions necessary to reconstruct the process starting from actors' responses. As a conclusion of this initial stage, a questionnaire was administered to LL actors to know how they prioritize the application of digital technology. Each question is related to a flow of information represented in Fig. 1.

V. Discussion and Future Work

The comparison between the pilot study presented in [6] and the second case study introduced above, shows that the process modelling is valuable for information exchange, and constitutes a knowledge base for cost-benefit analysis. The proposed set of diagrams was evaluated as comprehensive for the representation of different aspects related to the adoption of the technology. At the same time, there is a need to develop a flexible methodology to be adapted to different LLs. In fact, a first emerging difference is related to the level of introduction of the technology in the two LLs. In the case of precision irrigation the technology was already adopted in an experimental area of the farm, and a phase of evaluation of the technology is currently in course. Thus, it was relatively easy to extract information from an interview to key informants which are already using the technology, and obtain data both related to the process *after*, and to the process *before*. Instead, in the case of Pecorino Toscano, the LL is evaluating different technological solutions through a co-design process. Since the initial meetings, the collaborative team was capable to express problems, goals and describe the process as-is (i.e. the process *before*) and produced as an outcome of this activity a diagram (Fig.1) that was easily converted into a structure diagram (Fig.2), as part of the process modelling set. Next stages will be crucial for defining which technological solution to analyse in the context of CODECS and which activities to carry out for eliciting information for the process modelling. LLs are very different among each others and in future work we will target new LLs; this will contribute to continue the adaptation of the process modelling methodology to new needs arising, until a stable procedure will be reached. In a final stage, to ensure that the representations produced are useful and understandable, we will evaluate them according to the

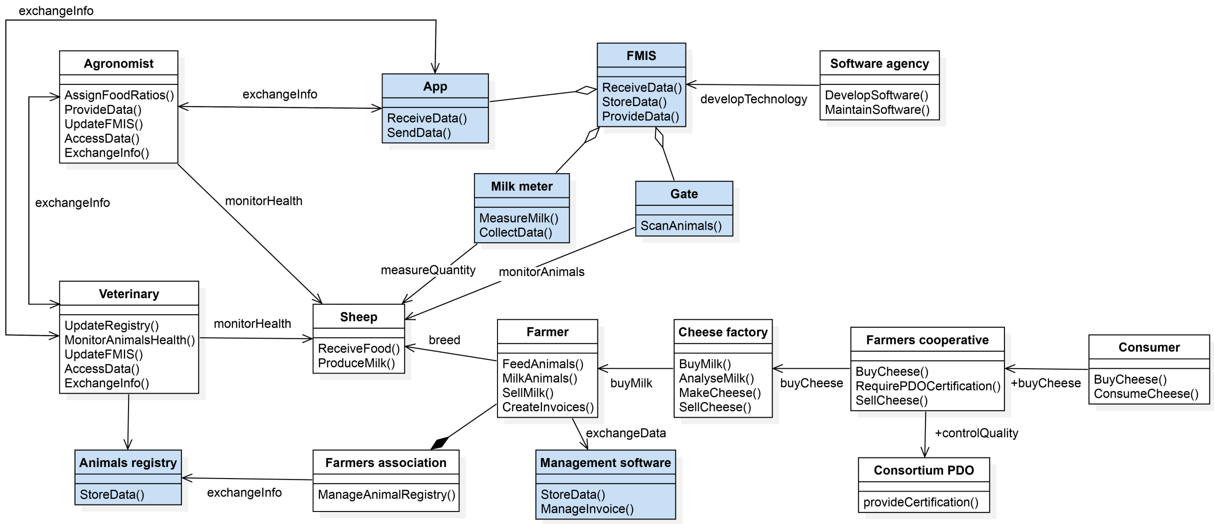

Fig. 2. Structure diagram with actors, activities and relation in formal UML notation. Technological components are highlighted in blue.

Technology Acceptance Model (TAM) [14]. Specifically, we will use standard questionnaires to evaluate the constructs of Perceived Ease of Use (PEOU), Perceived Usefulness (PU) and Intention To Use (ITU), as done by other authors [15].

Conclusions

This paper presents preliminary results arising from the ongoing research project CODECS. LLs involvement helps to address emerging challenges related to the adoption of digital technologies while performing research in real agricultural contexts. Diagrammatic notations are the common language for information exchange between different actors, and MoDRE strategies allow to create formal representations in support of further analysis and assessment. The aim of this study is to demonstrate the applicability of the process modelling to Pecorino Toscano LL, which is carrying out co-design activities to define the FAS, and provide adaptation to the methodology currently under development. Future challenges include the application of the methodology to 20 LLs in CODECS while carrying out adjustments to the methodology for data collection and modelling, along with a final evaluation within LLs.

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