Towards a Method for Modelling Socio-technical Process Transformation in Digital Agriculture

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***Abstract*—*[Context and motivation]* Digitalisation in agriculture is a socio-technical process that involves multiple stakeholders with diverse backgrounds and skills, e.g., in farming or technology. Capturing process transformation requires focusing on different dimensions, i.e., system structure, process flow, and actors' goals. Model-driven requirements engineering (MoDRE) techniques can offer the means to elicit and represent this multi-dimensional information. *[Question/problem]* This paper explores how MoDRE techniques can facilitate information exchange within interdisciplinary teams engaged in agricultural process transformations driven by digitalisation. *[Principal ideas/results]* We present a preliminary method for socio-technical process modelling consisting of (i) a set of different MoDRE diagrams, namely UML, iStar, and BPMN, and (ii) a procedure to collect the data required for the definition of the diagrams. The method is developed according to design science, and is currently evaluated through an action research study in the context of a living lab (LL, i.e., a network of stakeholders involved in a common socio-technical system) belonging to the agricultural domain. The evaluation with agronomists, practitioners, domain experts, and software engineers shows that the models developed are effective and understandable. Furthermore, the discussion over the completeness of the diagrams led to improved versions of the representations, considering different dimensions of the process transformation. *[Contribution]* There is little empirical evidence on the use of MoDRE techniques in real-world environments. This study fills this gap by developing a preliminary method for socio-technical process modelling in co-design contexts. The presented evaluation confirms the feasibility of the proposal.**

***Index Terms*—requirements elicitation, socio-technical systems, agriculture, living labs, process modelling**

I. Introduction

Digitalisation is a socio-technical process that brings radical transformation, and its impacts can be evaluated from various perspectives such as social, institutional, economic, environmental, and technological [1], [2]. This is particularly true for the agricultural domain, which, starting from traditional practices, is experiencing a disruptive paradigm shift due to the introduction of digital technologies [3]. Recent studies highlight the importance of adopting an interdisciplinary approach when developing innovative solutions for agriculture [4] and consider the impacts of the adoption of such technologies in real rural contexts [1], [5], [6]. However, interdisciplinary research and the direct involvement of multiple stakeholders bring complexity to information exchange and communication challenges may arise at multiple levels. In these contexts, effective communication can be supported by model-driven requirements engineering (MoDRE) techniques, which leverage diagrammatic notations to represent various aspects of the systems requirements, e.g., functionalities, structure, goals, data, processes, and workflows [7]. MoDRE techniques include iStar [8], KAOS [9], URN [10], BPMN [11], and others, and have a central role in requirements engineering (RE) research [12], [13].

Despite the several research contributions on MoDRE techniques, Mavin *et al.* [14] highlight a lack of empirical studies on the applicability of MoDRE to real-world environments with a relevant *social* component. Furthermore, to our knowledge, most of the existing studies focus on modelling the system/process to-be, or the system/process as-is, while none of the studies focus on representing the *transformation* of the socio-technical system or process. In our research, we aim to fill this gap by developing and assessing a method based on MoDRE for supporting communication exchange within interdisciplinary teams aiming to model socio-technical process transformation. The final goal is to use graphical models to enable stakeholders to reason about the impacts of digitalisation in agriculture. The method is applied in the context of the Horizon Europe research project *Maximizing the co-benefits of agricultural digitalisation through conducive digital ecosystems* (CODECS) [15]. In the context of CODECS, we interact with 20 Living Labs (LLs), i.e., communities of local practices, including farmers, knowledge intermediaries, stakeholders, and policymakers carrying out co-design activities for addressing common goals, e.g., improve productivity, enhance product quality [16]. The objective of CODECS is to identify the process transformed by the introduction of digital technology and provide a comprehensive representation of this transformation. This should be understandable to all stakeholders involved in the LLs and useful for further impact analysis, e.g., cost-benefit analysis, carried out by experts in agricultural economics and social science.

The current paper presents a preliminary MoDRE-based method to model process transformation, which will be applied in the 20 LLs of the CODECS project. We developed the method through a design science cycle [17], and we implemented and evaluated it in a LL concerning cheese production, involving 4 software engineers, 7 domain experts in agronomy and approximately 30 LL stakeholders in total. We gathered feedback on the method's application from the domain experts, who were actively involved in its implementation. The output of the evaluation will be used to refine the method into precise guidelines for its wider adoption in the other LLs. Supplementary material is reported in [18].

The remainder of the paper is structured as follows. Sect. II presents the methodology applied in our study and provides an overview of the design science steps completed. In Sect. III, we introduce the Socio-Technical Process Modelling method that we propose as a treatment. Sect. IV describes the implementation of the method through action research and the evaluation carried out with LL stakeholders in three focus groups analysed through a thematic analysis. In Sect. V, we discuss the findings and implications of our study, considering its broader relevance for the community of global practices. Sect. VI explores potential threats to the validity of our research. Finally, in Sect. VII, we present conclusions and outline directions for future work.

II. Methodology

In this paper, we aim to address the following research question (RQ): *How can MoDRE techniques be successfully applied in co-design contexts for the representation of a process transformation?* Given the "how" nature of the RQ, we adopt the Wieringa's design science methodology [17] to develop an artifact that addresses the RQ. Table I summarises the steps we completed so far, i.e., all the steps of the first cycle, namely *problem investigation*, *treatment design*, *treatment validation*, *treatment implementation*, and *evaluation*.

To answer the RQ, we perform our study in a co-design environment in the framework of the EU project CODECS. The research group involves software engineers and agricultural stakeholders. In addition, we interact with a community of local practices constituted by the 20 European LLs participating in the project. In the following, we give an overview of the different phases, and then we focus mainly on describing our (preliminary) method (Sect. III), as well as its implementation and evaluation (Sect. IV). The future phases will consist of additional design science cycles to refine the proposed method.

A. Problem investigation

The research started in mid 2021 from the input of the partners of the CODECS Consortium, mainly composed of agronomists and sociologists, who involved the second and last author of this paper in the project definition. Their support was required given the need to use graphical representations to facilitate stakeholder communication, and given the expertise of the authors on MoDRE techniques applied in previous European projects, e.g., LearnPAd [19].

1) Focus groups: We organised two focus groups with the project coordinator, who collected ideas and needs from 33 project partners through informal meetings. The goal of the focus groups with the coordinator was to define the initial concept of the process modelling approach. This phase resulted in the submission of the project proposal (September 2021), which included the description of the concept. The proposal was reviewed and approved by the European Commission (EC) in February 2022.

2) Observation: On July 19, 2022, we performed an observation study through a one-day visit to a fruit farm[1] in Tuscany, Italy which is adopting a precision irrigation technology. This involved 10 participants, and the output was a textual report describing the farm context, i.e., technology, stakeholders, and activities. The report was produced by the agronomists who participated in the visit. The goal of the activity was twofold: i) understand a LL context that could be similar to those of CODECS; ii) understand what type of process-relevant information could be collected about a LL by domain experts without software engineering expertise, i.e., the typical profile who was expected to collect information to be later used for modelling, according to the initial concept of the approach.

B. Treatment design

This step comprised two main activities: a non-systematic literature review and internal focus groups.

1) Literature review: The review was conducted by the first author, a PhD student, and supported by the other authors. We reviewed previous studies in the MoDRE field addressing similar challenges and we considered all the principal MoDRE notations, i.e., BPMN [11], iStar [8], Tropos [20], KAOS [9], URN [10], UML [21], SeeMe* [22]. For the sake of space, in the following we summarise previous research on goal-oriented approaches (iStar in particular), UML, and BPMN, as they will be used in our approach.

Goal-oriented approaches [13], among the most common MoDRE techniques, focus on understanding the objectives and desired outcomes that stakeholders aim to achieve, and are adopted for balancing multiple, sometimes conflicting, goals. Previous research adopted the goal-oriented iStar notation, formerly i* [8] for requirements analysis of normative aspects in socio-technical food traceability systems [23], while other authors integrated goal and business process models for enhanced information system analysis [24]. The Unified Modelling Language (UML) [21] is a comprehensive software engineering language including different types of structural diagrams (e.g., class diagrams) and behavioural ones (e.g., sequence diagrams). UML is widely used in industry for requirements representation, according to the survey by Wagner *et al.* [25]. Regarding process modelling, BPMN [11] is the most prominent notation, having a large diffusion among practitioners. BPMN models are a means for information

[1] http://www.illuminatifrutta.it. *Last visited 8 March 2024.*

TABLE I: Design science research steps

DS step	*Activity*	*Participants*	*Output*
Problem investigation	2 focus groups under request of EU project consortium	3 people 1 project coordinator collecting needs from 33 participants (20 living labs and 13 institutional partners)	CODECS project proposal submitted Concept of the process modelling approach
	Observation 1-day visit to fruit farm precision irrigation technology	10 people	Report by agronomists
Treatment design	Literature review (non systematic)	4 people	Preliminary RQs Improved concept Requirements definition
	Brainstorming focus group with SE experts	5 people	Evaluation of project constraints Preliminary RQs Modelling languages chosen Improved concept Procedure draft Requirements definition
Treatment validation	Focus group on pilot study precision irrigation technology	6 stakeholders	Feedback on concept Requirements refinement
	Plenary presentation CODECS general assembly	around 80 people	Feedback on concept Requirements refinement
Treatment implementation	Action research Pecorino Toscano LL FMIS technology	around 40 people (LL stakeholders and research group)	Socio-technical process modelling artefact set of diagrams representing the transformation of a cheese production process
Treatment evaluation	3 focus groups	11 people researchers agronomists practitioners	Requirements refinement

exchange between engineers and business analysts [19]. The language supports advanced techniques, even AI-based, for data analysis, such as process mining [26], or change impact analysis [27]. Law et al. [28] developed a user-centred methodology based on BPMN diagrams for requirements elicitation.

The literature review resulted in preliminary RQs, an improved concept, and an initial definition of the requirements—cf. the high-level requirements in our supplementary material [18].

2) Focus groups: The treatment design step also involved internal focus groups with software engineering experts, i.e., the authors of this paper. These are researchers in software engineering, experts in formal and graphical languages, human-computer interaction, and agritech. The focus groups were mainly devoted to brainstorming and several activities were conducted, such as evaluation of the project constraints, consolidation of RQs, selection of modelling languages, drafting of the procedure, and requirements definition. In the *treatment design* step, we designed a method based on three graphical notations from the MoDRE field, i.e., iStar, UML class diagrams, and BPMN. In selecting the notations we considered: (i) the initial requirements, which specified the need for the representation of socio-technical goals and relations (iStar), structural system aspects (UML), and process aspects (BPMN); (ii) the prominence of the notations in the literature; (iii) the ease of modelling, granted by the tool support offered for UML and BPMN, and by the flexibility of iStar, whose models can be represented with common graphical tools (LucidSpark, in our case); (iv) the authors' previous experience in the notations. We adapted and simplified the notations based on our previous experience, to maximise understandability for stakeholders with no expertise in the notations, as also specified by the initial requirements.

C. Treatment validation

In this step, we validated the concept in a pilot study on the case of precision irrigation technology in use in the Italian fruit farm. We presented the pilot study in [29].

1) Focus group: In November 2022, we organised a focus group with the agronomists who provided the report during the problem investigation phase. The output of this phase was the feedback on the artifact concept and requirements refinement.

2) Plenary meeting: During the first general assembly of CODECS held in December 2022, we presented the pilot study and discussed the concept of the method with the project partners. Around 80 people participated in the meeting.

D. Treatment implementation and evaluation

After completing the first three design science steps, we carried out an action research study [30] that is presented in detail in the following sections. We interacted with *Consorzio Pecorino Toscano*, a CODECS LL dealing with the introduction of a farm management information system within a cheese-making process. We implemented a treatment based on a set of diagrams and evaluated it with software engineers experts in the notation, experts in agricultural economics, and stakeholders from the LL. The experts in the notations evaluated if the diagrams were sufficiently rigorous from a syntactic perspective, while the focus groups with agronomists evaluated the understandability and effectiveness of the representations. The feedback allowed us to fine-tune the method and obtain requirements to proceed to a new design cycle. This future design cycle will be focused on the development a set of guidelines to elicit information from LLs. The guidelines will be used by LL contact points, typically agronomists, to collect the information to define the models. The requirements document at the current stage of development is available in our supplementary material [18].

III. Socio-technical Process Modelling Method

The proposed method consists of: (i) a set of MoDRE notations to describe all the elements of interest related to a process of transformation occurring after the introduction of digital technology within a socio-technical system; (ii) a preliminary procedure to collect the required information and represent the models.

Notations. The process transformation is emphasised by qualitatively highlighting the differences in the process *as-is* (before) and in the process *to-be* (after). To ensure completeness, we model the transformation of a process focusing on three complementary dimensions (structure, goal, and process), which can be represented through different notations:

- *Structure*: the UML class diagram provides an overview of the process structure, i.e., actors, resources, tools, and infrastructures involved in the process to-be and the relationships among them [21].
- *Goal*: the iStar diagram models the goals of the process to-be focusing on the intentional, social, and strategic dimensions [8];
- *Process*: the BPMN diagram [11] [26] [19] represents the detailed flow of the process, including actors' tasks, procedures, and communications. Multiple diagrams are developed to represent both the process as-is and the process to-be. An overlapping visualisation allows comparisons between the overall process before (as-is) and after (to-be) the introduction of digital technology.

The iStar and UML diagrams only focus on the process to-be in order to simplify the overall representation, considering that the core models to visualise the process transformation are the BPMN diagrams. This was a pragmatic decision of the authors. The method for creating the set of diagrams is designed to be lightweight and with few interaction loops, accounting for the stakeholders' limited time.

Procedure. The procedure we followed for creating diagrams within the LL is as follows:

1) **Input data collection:** In this phase, a software engineer in charge of creating the diagrams performs one or more visits to the context of the process transformation, e.g., the farm in our case. The software engineer is accompanied by one or more domain experts, e.g., agronomists. The team performs unstructured interviews with the available stakeholders to capture information about the envisioned system structure (stakeholders and components), the goals, the process as-is and the process to-be. After the visit, the domain experts write an informal natural language document explaining the different aspects and/or informal diagrams. At this stage, we define neither an interview script, nor a specific structure for the document. Precise guidelines will be defined when the method is finalised after this initial design cycle.
2) **Formalisation:** The captured information, together with the knowledge acquired during the visit, is used by the software engineer to design the diagrams. A focus group is organised with other software engineers with high expertise in each notation to ensure that the presented diagrams are syntactically and semantically correct. This step is required as a software engineer is unlikely to have formal expertise in all three notations.
3) **Feedback collection:** A focus group is organised involving the domain experts, in which the diagrams are shown, and a discussion is carried out to capture possible misunderstandings, complete the diagrams with the additional information elicited, and acquire feedback on effectiveness and understandability. Additional loops can be introduced to validate the diagrams.

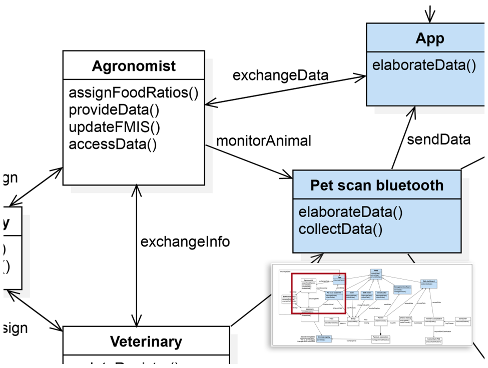
IV. Treatment Implementation and Evaluation

We conducted an action research study by applying the method in a LL participating in the CODECS consortium. After the first data collection, we developed the diagrams and organised three focus groups to evaluate the artefact.

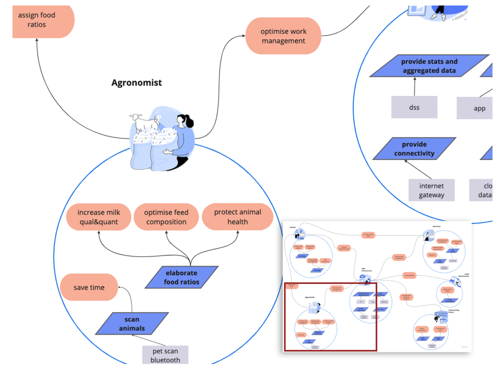
A. Case and Subject Selection

We selected *Consorzio Pecorino Toscano*, an Italian LL based in Manciano, Tuscany and focused on the activity of sheep breeding and pecorino cheese production. The LL is working on introducing a smart farming solution in the cheese production process.

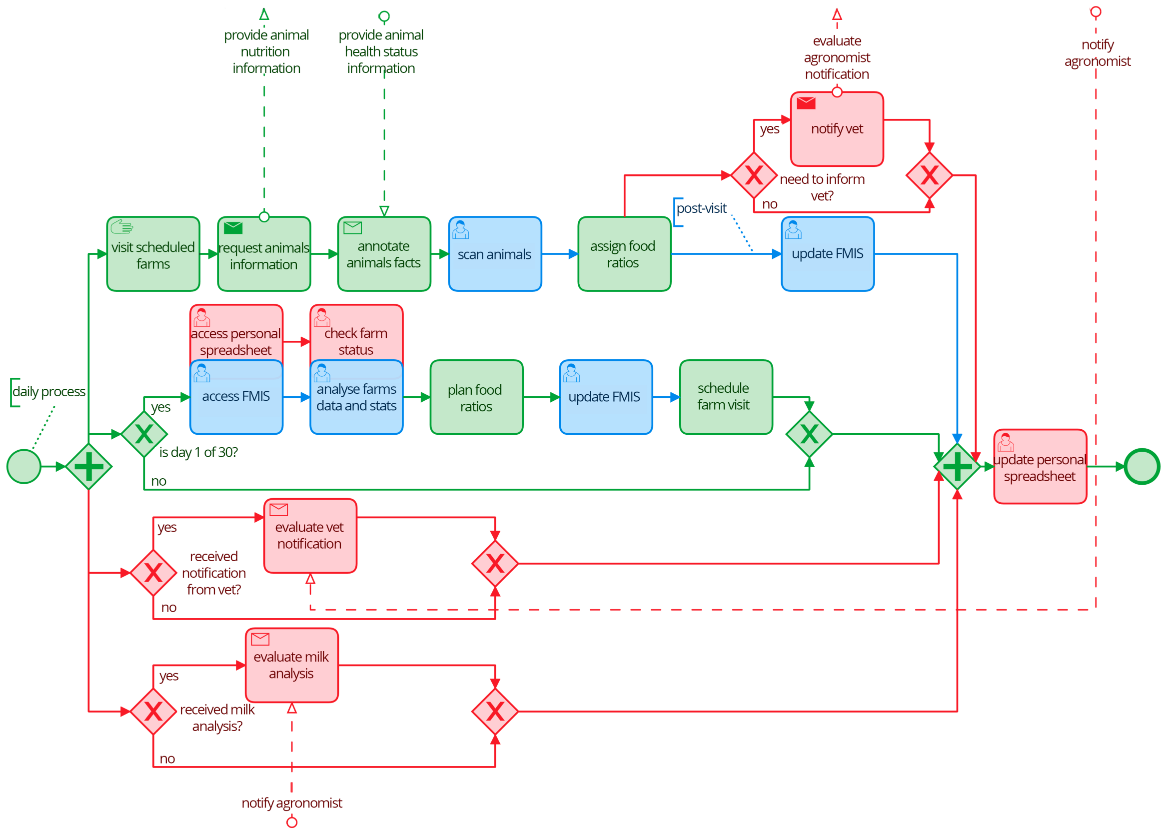
The LL involves different stakeholders, i.e., farmers, researchers, the farmers' cooperative, the consortium of producers, the cheese-making factory, and the technical advisors working closely together with the farmers. Local administration such as the municipality of Manciano and the Tuscany



(a) UML class diagram



(b) iStar goal diagram



(c) BPMN diagrams overlap

Fig. 1: Models representing part of a cheese production process transformed by the introduction of a farm management information system

Regional Administration are also participating in some LL activities.

The LL is built around the development and evaluation of a farm management information system (FMIS) including a series of technologies aimed at supporting the work at various levels. The final system will grant interoperability among several technologies, such as a mobile application to monitor animals' health status, food ratios and milk production; smart collars to protect animals against wolves; and a blockchain-based system for farm-to-fork traceability.

A prototype of the app is currently in use by technical advisors, while additional components are under evaluation. Participatory activities are being carried out in the LL for the co-design and evaluation of the digital technology.

In previous work, we described the initial phase of the co-design activity and some preliminary results [31].

B. Data Collection and Analysis

a) Farm Visit and Data Collection: The authors of the paper (software engineers) visited the LL multiple times dedicating half a day to interacting with a group of around 20 people, including all stakeholders mentioned in IV-A.

The first visit to the cheese-making farm in Manciano and to a sheep breeder was on November 11, 2022; this was followed by another meeting with the LL team in Manciano, on February 24, 2023, and a meeting at the Department of Agricultural Economics of the University of Pisa on May 26, 2023. After the meetings, the agronomists produced additional material, i.e., an informal diagram depicting all the elements of interest for the LL.

Data collected in this phase aimed at describing the system structure, the digital process currently under development, and the change with respect to the traditional process.

b) Formalisation: Based on the input data, the first author created the formal diagrams, and the other authors revised them and provided feedback according to their expertise.

The phase of internal revision was completed on October, 6, 2023 and led to 4 main changes to better comply with the grammar of the notations and user experience. A logbook is kept to document the iterations and is shared in the supplementary material.

c) Feedback Collection: The diagrams were used to further clarify certain aspects of the system in focus groups with the agronomists. Three focus groups were organised with three different groups on October 23, 2023 (FG1), November 24, 2023 (FG2), and December 4, 2023 (FG3) respectively. Four participants took part in FG1 (P1, P2, P3, P4); the group was composed of three females and one male, one expert in agricultural economics (P1), one in animal production (P2) and two software engineers with expertise in formal notations (P3 and P4). Six participants participated in FG2 (P5, P6, P7, P8, P9, P10): three females and three males, three experts in agricultural economics (P5, P6, P7) and three software engineers (P8, P9, P10). Five participants took part in FG3 (P11, P12, P13, P14, P15): four females and one male, two practitioners, i.e., an agronomist (P11) and a vet (P12) who are the technical advisors involved in the LL, one expert in animal production (P13) and two software engineers (P14 and P15).

The software engineers were the same in the focus groups and moderated the discussion. During the focus groups, together with the revision of the diagrams, questions were asked about the comprehensibility, effectiveness, and completeness of the representations. The focus groups were recorded and transcribed for analysis.

The evaluation led to substantial changes in the diagrams. In FG3, which was held with practitioners, an improved version of the diagrams was discussed, which was the outcome of the feedback received in FG1 and FG2. The presentations containing the diagrams discussed in the focus groups are available in our replication package, along with all versions of the diagrams. Feedback is tracked in the logbook.

d) Diagrams: Excerpts of the final versions of the models are reported in Fig. 1. Fig. 1 illustrates parts of the diagrams developed in the CODECS LL where a farm management information system is introduced to monitor milk production within a cheese-making process (cf. Sect IV). The system is designed to share data among the actors involved in the process (e.g., agronomists, veterinaries, farmers).

Fig. 1a contains a portion of the UML class diagram with a detailed view of the class *Agronomist* and neighbouring elements. The new classes introduced by digital technology are in light blue. In Fig. 1b, the iStar diagram represents the goals, activities and relationships of the agronomist within the cheese-making process. For this type of diagram, the authors adopted a modified style for the notation by creating an enhanced version consisting of icons for representing actors and a different style for the symbols. This is to obtain more user-friendly representations and to improve readability.

Fig. 1c is an overlap of two BPMN models focused on the pool of the agronomist: a first diagram describing the process carried out by the agronomist before the introduction of technology, and a second diagram representing the new process introduced by the digital infrastructure. In the picture, the new participants, activities and gateways introduced by the technology are in blue; in green the activities and gateways that do not change; in red the activities and gateways that are not present anymore.

The *data analysis* consisted of a thematic analysis [32] of the transcriptions of the focus groups with experts. It was performed by the first author, and the last author revised it for understandability and coherence with the transcripts.

C. Results

This section presents the results obtained from the thematic analysis. For each type of diagram, namely UML, iStar and BPMN, two main questions were discussed related to the *understandability* and *effectiveness* of the representations. Moreover, a third question about the *completeness* of the representation supported the discussion about missing elements and led to improved versions of the diagrams. Understandability refers to the clarity and accessibility of the diagrams to a wide range of stakeholders, including LL contact points, researchers from different domains and relevant actors involved in the process evaluation. Effectiveness refers to the ability of the representations to serve their intended purpose in facilitating process assessment and communication. Completeness refers to the extent to which the diagrams accurately and comprehensively capture the essential entities, relationships, and layers concerning the dimension represented.

Table II contains a map of the identified themes, which are discussed in the following, while completeness is discussed as an additional dimension in Sect. V.

1) Structure Diagram UML

a) UML Understandability: The feedback on understandability confirmed that participants in all the focus groups generally agreed that the diagram was clear.

In particular, P1 and P2 expressed their appreciation for the *useful colouring*, referring to the use of light blue to highlight classes representing technology. This requirement was suggested by a domain expert in a previous focus group carried out during the treatment validation phase (ref. Table I). The request was to put more emphasis on technology and identify with different colours the digital from the non-digital. During the evaluation, the domain expert, who also took part in FG1, confirmed the effectiveness of the new solution and the other participants unanimously agreed.

Despite the positive feedback, some difficulties emerged regarding *hard symbols interpretation*. Some participants found it difficult to interpret specific elements of the notation, such as the different types of association connectors (i.e., aggregation, composition) or the direction of some arrows in direct associations. As in the previous theme, difficulties in distinguishing attributes and methods inside the classes had already emerged during the validation. This suggested avoiding class attributes and opting for a simpler representation with class names only (see Fig.1a). Thus, to maximise the understandability of this diagram while minimising the readers' effort, a simplified version was produced, consisting solely of boxes with class names, and main operations performed by the class. This version with improved readability was presented in FGs and evaluated positively. An advanced version with expanded boxes is still available for stakeholders interested in a deeper analysis.

b) UML Effectiveness: In general, the participants agreed that the diagram is "very effective" (P5) and "very useful" (P1). To assess effectiveness, participants considered potential usage scenarios for this type of diagram in the context of the planned LLs activities. Specifically, all participants in FG1 commented that having a standard representation is *useful for comparison*. Referring to process modelling activities carried out in parallel in different LLs, P1 stated: "It could be useful for every one of us to see the differences among LLs". After analysing the diagram, P1 also suggested that the representation could be potentially subject to further *reuse and adaptation* by specific actors: "The consortium could use the same diagram in different situations". Another aspect that emerged was the *consistency with the scientific body of knowledge* adopted in the LLs, namely Ostrom's socio-ecological System framework [33]—which is the reference framework for CODECS. Ostrom's framework consists of a multi-level scheme of concepts and variables to describe systems in terms of resources, governance systems, actors, and knowledge. The framework relies on a problem-based approach, thus LLs are asked to prioritise a problem and address a *focal action situation*, i.e., a situation where components of a socio-technical system interact to provide an outcome. Overall, the participants found the model consistent with the principles of CODECS (P1; P2; P3; P5). P1 declared: "The representation seems in line with what was discussed previously," adverting to a preliminary activity carried out by the LL to collaboratively define the focal action situation to be assessed in CODECS.

2) Goal Diagram iStar

c) iStar Understandability: Generally, participants confirmed that they could understand the notation and provide feedback on the diagram. The participants agreed to *keep the representation simple*. In fact, being the goal model focused on strategic aspects, the representation should be limited to a small set of actors who are internal to the process. Moreover, P14 suggested: "We could deviate a bit from the standard of the notation in favour of readability". This diagram was globally evaluated as clearer than the UML diagram, however some participants encountered difficulties with understanding certain symbols. This resulted in the theme *hard symbols interpretation*. For example, additional clarification was requested in all FGs to explain the difference between goal and quality. Although in an additional iteration after FG1 and FG2 we tried to simplify the notation and decided to represent the goals and qualities in more distinct styles the confusion persisted in FG3. After carefully evaluating the feedback, we decided to avoid the distinction between the two concepts and use only a more general abstraction of "actor goal" encompassing both goals and qualities. The new version is represented in Fig. 1b.

d) iStar Effectiveness: The diagram was evaluated as extremely useful for early discussion on strategic aspects, and participants highlighted that the goals could be useful for *monitoring policies and interoperability*. P1 and P2 asked to add a boundary with the public institution responsible for the Animal Registry with a main dependum task "Share animals data." By adding this element, the group aimed to highlight that it is extremely important to collaborate with public institutions to ensure interoperability between the FMIS and the Animal Registry in the process to-be. To confirm this, P4, specified "This kind of representation related to the goals helps to establish if there are potential conflicts between the actors," which could be particularly useful for policymakers.

TABLE II: Thematic map

Questions	*Themes*
UML Understandability	Useful colouring, Hard symbols interpretation
UML Effectiveness	Useful for comparison, Reuse and adaptation, Consistency with the scientific body of knowledge
iStar Understandability	Keep the representation simple, Hard symbols interpretation
iStar Effectiveness	Monitoring policies and interoperability
BPMN Understandability	Linearity, Useful colouring, Consistency, Hard symbols interpretation
BPMN Effectiveness	High level of detail on the process workflow, Multiple objectives of the representation, Immediate detection of advantages
Methodology	Tool for analysis, Effectiveness of visual representations, Reuse of the models, Procedure for co-creation of the diagrams

3) Process Diagram BPMN

e) BPMN Understandability: Participants agreed that the representation is very clear and the single views are *consistent* with each other (P3).

P5 appreciated the *linearity* of the diagrams: "These representations with straight lines are clean and very understandable." Furthermore, participants discussed the theme *useful colouring*. In fact, they particularly appreciated the overlapped representation enabled by the use of different colours. P2 said: "I really like the idea of using the colours, I think this is very intuitive." P11, despite appreciating the use of colours for representing the transformation, claimed that they had difficulties distinguishing the blue elements from the green ones and suggested reflecting on the use of alternative colours. Furthermore, the theme *hard symbols interpretation* emerged again in FG3. In fact, both participants had difficulties in understanding the meaning of the gateways. Moreover, P12 said: "I don't pay attention to the small icons inside the boxes containing the actors' tasks."

f) BPMN Effectiveness: All participants appreciated the overlapping view (see Fig. 1a) and evaluated it as particularly effective in presenting the process transformation. The participants agreed that the process diagram presents a *high level of detail on the process workflow* and actors' tasks. Referring to the multiple views developed, each one depicting an actor's pool, P1 commented: "The process is seen from the perspective of the agronomist, then from the point of view of the vet, from the farmer, from the factory…they are all there, well done."

Reasoning on possible usage scenarios, P5 highlighted the *multiple objectives of the representation*: "These representations are very effective and can support the design of the service helping to decide how to distribute tasks among actors and how to manage a service in a different scenario; for example, we could have the same process with different actors involved and different task distribution." Furthermore, P1 confirmed that the diagram supports the *immediate detection of advantages*. In fact, having a view of the process from the perspective of every single actor is useful for the detection of important features: "presenting the single point of view, the diagram really shows who has the costs, who has the benefits. In the end, it will emerge thanks to these diagrams."

4) Process Modelling Method

A final time slot in the focus groups was dedicated to a common discussion about the proposed method. Participants confirmed that the global modelling is very complete, effective and detailed. Furthermore, during the discussion about some scenarios of application of the diagrams, the main theme was to adopt process models as a *tool for analysis*, especially oriented to reflect on costs and benefits. Moreover, participants also agreed on the *effectiveness of visual representations*. During the discussion in FG1, it emerged that visual representations have the main advantage of being synthetic and immediate. P1 said: "Visual representation is a good support for memory and is more effective than reading a textual document, which is a more time-consuming activity." In the same FG, it was discussed the theme of the *reuse of the models*, understood as the application of a model developed within a context to a new similar context. The aim could be to assess which changes are necessary to introduce the technology in the new context. One last concern was related to the need to set up a common *procedure for co-creation of the diagrams*. The discussion started in FG1 with the following question by P1: "Will the other LLs do the diagrams on their own?" All of the participants agreed that creating diagrams for LLs could be a challenging task, and experts in the notations are required. During the meeting, the participants discussed the initial proposal of a procedure based on guidelines for LL contact points and a template for data collection. This will be further explored in the upcoming design cycle.

V. Discussion

a) Effectivenes and Understandability: The outcome of the thematic analysis confirms that, generally, the participants evaluate the models as effective and understandable. The overall feedback on the method is positive, confirming the willingness of the participants to use the method as an analysis tool and a companion to technology demonstration.

b) Completeness: The representations facilitate stakeholders in identifying incompleteness issues, thus fostering discussion and leading to more representative models. During the discussion of the UML class diagram, an initial question asked participants if they were able to find all actors, resources and relations that are part of the process structure. They were suggested to consider that this kind of model can be extended to the representation of the wider system, including both internal and external actors. Several participants agreed that the representations, while already comprehensive, could be further enhanced with *more complete elements*. In fact, participants reported that some elements or relations were missing. For example, it was decided to add a link between the software agency, the agronomist, and the vet. This relation was considered relevant to highlight the information exchange during the co-development of the mobile application, and to provide the analysts with a clear indication of the actors directly involved in the design of the system. Then, moving the discussion to the iStar diagram, participants were asked to ensure that all the relevant stakeholders, goals, tasks, and dependencies were adequately represented in the model. Despite the feedback being globally positive, participants found that some resources or tasks were missing, and some elements needed to be better specified. For example, a goal mismatch was reported in the boundary of the vet and it was agreed to replace *milk productivity* and *milk quality* with *animals health*, being the first seen as a consequence of the latter.

c) Limitations: A limitation emerging from FG1 and FG2 was related to evaluating the BPMN diagrams. In both focus groups, the process diagrams were evaluated as extremely interesting, providing very detailed views of the process workflow at the actor's level, and helping to identify the risks and advantages of process transformation. However, it was not possible to collect precise feedback, as the evaluation team did not include the practitioners directly involved in the process. Thus, a third focus group (FG3) was organised with practitioners who were able to provide accurate information on activities, frequency and relations among actors both about the process as-is and the process to-be. This confirms that to reach a holistic representation of a process we should include a feedback loop with *all* representatives of the LLs, including practitioners.

A major concern emerging from the analysis is the need to familiarise with the notations to understand the diagrams thoroughly. This is especially the case of the UML diagram, which is perceived as the most effective in representing the potential extent of the transformation, but at the same time is regarded as the most challenging to understand. On the one hand, agronomists accept the effort to learn the proposed notations with the result of enlarging the scientific body of knowledge shared by the community of practices involved in the LLs. On the other hand, a negotiation has been carried out by the authors and the agronomists to simplify the notation, while maximising the completeness of the representations. A tension between understandability and completeness frequently emerged. In fact, as already discussed in IV-C, some participants found difficulties in decoding fine-grained symbols on the diagrams. At the same time, analysing a diagram from multiple perspectives contributes to increasing the number of elements in the representation. This point was discussed while examining the UML diagram, and some participants suggested creating multi-layer representations, i.e., having multiple models that focus on different levels of a system. For example, there can be models that represent the minimal elements of the system, as well as specialised models that focus on a subset of the system. Additionally, complementary models can represent different states of the system, such as the set-up and fully operational stages.

d) Solutions: There is no single solution to the tension between understandability and completeness, and we have been working on tackling the problem from different angles. In some cases, the solution was to maintain the symbols and rely on the legend as a support tool for users. In other cases, the evaluation group decided to maximise the readability of the diagrams by avoiding the use of advanced symbols, also in line with recommended practices [19]. The authors also introduced additional conventions in the representations. For example, in the iStar diagram, in addition to the use of an aesthetically enhanced notation, it was decided to represent the technology introduced in the system within an actor boundary placed in a central position. This was to emphasise the technological components which are at the centre of the transformation. In general, multiple iterations helped to improve the diagrams and find optimal solutions applicable to the whole method.

e) Summary: The active participation in the focus groups showed that the agronomists clearly understood the notations and were able to provide feedback. Participants evaluated the method as effective in supporting the analysis of digitalisation at multiple levels, and iterations led to improved diagrams, confirming the proposal's feasibility. Thus, we can conclude that the method leads to understandable and effective representations and can be successfully applied in co-design contexts for the representation of a process transformation.

VI. Threats to Validity

Construct Validity. The constructs considered in the evaluation include *understandability*, which assesses how accurately the meaning of the representations is conveyed; *effectiveness* of the method, which measures the usefulness of the representation for information exchange; and, to a lesser extent, *completeness*, which evaluates any missing elements in the representations. The definition of these concepts have not been detailed to the participants, which could have led to misunderstandings. However, we argue that the answers received show a correct comprehension of the concepts, which suggests that this threat is sufficiently limited.

Internal Validity. The selection of representation languages was based on preliminary requirements, and by pragmatic decisions. Different results may be obtained with different languages. The feedback was captured by the people who proposed the method, which could have caused a Hawthorne effect. To mitigate this, we asked the participants to be honest with their reflections, and the issues identified suggest the threat is limited. The thematic analysis is inherently subjective and was performed by the first author. To mitigate subjectivity, the last author reviewed the themes. In addition, we share quotes to support our themes, as well as the focus group transcripts [18].

External Validity. According to case-based generalisability [34], we argue that our results can apply to other LLs in the agricultural domain that are similar to our case, i.e., concerned with the production of food, and characterised by the presence of a preliminary prototype of a novel technology.

VII. Conclusions and Future work

This paper presents a preliminary method to model process transformation in the digitalisation of agricultural activities. The method uses different MoDRE notations, i.e., UML class diagrams, iStar, and BPMN to represent the transformation that occurred to a socio-technical process after the introduction of digital technology. After a first set of steps leading to the method and preliminary requirements, the treatment has been implemented and evaluated through action research in a real agricultural context, i.e., a LL participating in CODECS consortium. The LL deals with the introduction of a farm management information system to monitor a cheese-production process. We first carried out data collection by interacting with the LL, then, we developed the diagrams. Finally, we organised three focus groups with agronomists to evaluate the artefact. We performed a thematic analysis to analyse the outcome of the evaluation. The results show that the participants consider the models effective and understandable. Furthermore, the representations facilitate stakeholders in identifying incompleteness issues, thus leading to more representative models.

The feedback received in the evaluation allowed us to identify the main challenges and elicit requirements that will enable us to complete the method in subsequent design cycles, according to the solutions agreed upon by the revision team. By carrying out multiple focus groups, we iteratively assessed with diverse stakeholders the improved solutions and identified any residual issues that had not yet emerged from the previous evaluations, with the final objective of fine-tuning the method. The evaluation confirmed the feasibility of the proposal of adopting the method in several digitalisation scenarios in the domain of agriculture and helped us refine the requirements for completing the method in subsequent design cycles.

Future Works. Future works include the definition of a detailed procedure in the form of a set of guidelines for eliciting process-relevant information from LLs. A template will be defined to enable LL contact points to report the information in a structured manner. The captured information will represent the process transformation through the different notations. The procedure shall also include iterations with the LLs to ensure the completeness of the models. The final diagrams will, in turn, be used to qualitatively perform a cost-benefit analysis of the introduction of digital technologies in the process. This envisioned approach will be applied to the 20 LLs belonging to the CODECS project.

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