A Model-driven Requirements Engineering Method for Human-centered Digitalisation of Agriculture

Chiara Mannari

Department of Computer Science, University of Pisa, Italy
Institute of Information Science and Technologies "Alessandro Faedo" - ISTI, CNR, Pisa, Italy

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 research investigates how MoDRE techniques can support the information exchange within interdisciplinary teams involved in the representation of process transformation in digital agriculture. [Principal ideas/results] We propose a method for process modelling in agricultural domains consisting of (1) an artefact based on a set of different diagrams, namely UML, i* and BPMN, (2) a procedure based on guidelines and (3) a tool to support the co-creation of the diagrams within the context of living labs (LLs, i.e., networks of stakeholders involved in a common socio-technical system). We plan to apply the method through action research in the context of 20 European living labs in the agricultural domain and evaluate the method through standard user questionnaires. [Contribution] There is little empirical evidence on using MoDRE techniques in real-world environments. This study fills this gap by developing a method for socio-technical process modelling in co-design contexts.

Keywords
requirements elicitation, socio-technical system, agriculture, living labs, process modelling, end-user development

1. 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]. Agricultural digitalisation presents challenges with double-edged effects, generating potential winners and losers [2]. To minimise the risk of undesired consequences, it is important to early evaluate the impacts of digitalisation by performing an analysis of business processes transformed by the introduction of digital technologies. A preliminary task for such an analysis is to create clear representations of the process transformation considering multiple perspectives, such as social, economic, environmental and technological.

This leads to two issues. The first is gathering multiple stakeholders with different backgrounds and expertise to elicit the necessary information for the creation of the representations. The second is establishing a method for representing and exchanging information that enables to reach a common understanding across multiple domains. The solution to the first issue is carrying out activities within Living Labs (LLs). LLs are networks of farmers, knowledge intermediaries, stakeholders, and policy-makers that are constituted around an emerging problem and carry out interdisciplinary activities, such as assessment, co-design and co-development of solutions in real contexts, pursuing a human-centered approach [3]. The solution to the second issue is adopting Model-driven requirements engineering

In: D. Mendez, A. Moreira, J. Horkoff, T. Weyer, M. Daneva, M. Unterkalmsteiner, S. Bühne, J. Hehn, B. Penzenstadler, N. Condori-Fernández, O. Dieste, R. Guizzardi, K. M. Habibullah, A. Perini, A. Susi, S. Abualhaija, C. Arora, D. Dell'Anna, A. Ferrari, S. Ghanavati, F. Dalpiaz, J. Steghöfer, A. Rachmann, J. Gulden, A. Müller, M. Beck, D. Birkmeier, A. Herrmann, P. Mennig, K. Schneider. Joint Proceedings of REFSQ-2024 Workshops, Doctoral Symposium, Posters & Tools Track, and Education and Training Track. Co-located with REFSQ 2024. Winterthur, Switzerland, April 8, 2024.
chiara.mannari@isti.cnr.it (C. Mannari)
https://chiaramannari.github.io/ (C. Mannari)
0000-0002-5488-4150 (C. Mannari)

(MoDRE) techniques. MoDRE techniques, which leverage diagrammatic notations, can support the representation of various aspects of systems requirements, e.g., functionalities, structure, goals, data, processes, and workflows [4]. Model-driven approaches are widely used both for information exchange between engineers and different stakeholders and as design material for software development [5].

However, MoDRE is rarely applied in co-design contexts, and specialised software to develop the models and specific methods for the elicitation of information are typically oriented towards engineers and analysts. Furthermore, Mavin *et al.* [6] highlight a lack of empirical studies on the applicability of MoDRE to real-world environments with a relevant social component. Moreover, previous research [7] reflects on the suitability of RE methods at the time of smart rural areas and suggests the development of new innovative methods for agriculture.

This PhD research focuses on addressing these challenges. Using design science [8], we aim to develop and evaluate a method based on MoDRE to represent the transformation of processes in agricultural digitalisation to be applied in co-design contexts.

The research is carried out in the context of the four-year Horizon Europe project *Maximizing the co-benefits of agricultural digitalisation through conducive digital ecosystems* (CODECS)[1] that aims to develop valuable strategies to enhance the positive impacts of digitalisation. Our research team, a group from the Institute of Information Science and Technologies of CNR (Italy), is leading the task of process modelling, which will be carried out as empirical research through interaction with 20 European LLs.

The approach we propose, as already accepted by the international reviewers of CODECS, is to carry out process modelling to capture process transformation with the representation of processes before the introduction of digital technology (as-is) and after the introduction of digital technology (to-be). We aim to adopt MoDRE for the creation of standard and easy-to-read representations focusing on different aspects of processes, in order to reach an overall view of the occurred transformation.

2. Related Work

A literature review was carried out primarily to identify MoDRE methods that address the representation of process transformation in agricultural and rural domains in co-design contexts. We found that previous literature lacks a method to solve a similar challenge despite providing strategies to model specific aspects.

Ye et al. [9] developed a framework for enterprise integration of arable farming based on different dimensions corresponding to different models, i.e. resource, organisation, production management, and process. A large number of contributions, which are mostly engineers-oriented and enterprise-oriented, originate from research in Digital Twins [10]. Recent studies focus on the adoption of Digital Twins in the agricultural domain addressing the challenges related to virtually capturing the interactions between living systems and their environment [11].

Alternative approaches, which prioritise users' involvement, are mostly goal-oriented [12] and focus on understanding the objectives and desired outcomes that stakeholders aim to achieve. These are mostly adopted for balancing multiple, sometimes conflicting, goals. Previous research adopted the goal-oriented i* notation [13] for requirements analysis of normative aspects in socio-technical food traceability systems [14], while other authors [15] integrated goal and business process models for enhanced information system analysis.

Regarding business process modelling, BPMN [16] is the prominent notation, having a large diffusion among practitioners. BPMN models are a means for information exchange between engineers and business analysts [17]. The language supports advanced techniques, even AI-based, for data analysis, such as process mining [18], or change impact analysis [19]. Law et al. [20] developed a user-centered methodology based on BPMN diagrams for requirements elicitation.

To support the modelling of contexts characterised by a relevant social component, Prilla et al. [21] developed SeeMe, a notation supporting the modelling of uncertainties, which are considered funda-

[1] https://www.horizoncodecs.eu - Last access February 7, 2024

mental features typical of social systems. Recent studies aim to enrich the language connecting the notation with process modelling [22] and goal modelling [23].

3. Methodology

The research is being carried out as a design science project [8], making use of multiple research strategies and methods to create reliable and useful knowledge based on empirical evidence and logical arguments. The process of design science is articulated into five consecutive steps that will be further explored in 4.

Design science produces results that are relevant both to the research community and to a community of local practices. In the context of this research, the community of local practices is composed of the 20 European LLs participating in the CODECS Consortium.

We will carry out action research [24] applying and refining the method in the context of CODECS LLs that represent multiple contexts of digitalisation. Then, the method will be finally evaluated by LLs through interviews, focus groups and standard user questionnaires.

This PhD research received as input general problems experienced by the community of practices in CODECS. These can be summarised in three main points: (1) stakeholders want a clear understanding of how a certain technology impacts their business process; (2) there are information exchange issues in LLs due to different expertise and backgrounds of the stakeholders involved; (3) stakeholders ask to collaborate actively and be autonomous in the representation of systems and processes.

This led to the formulation of three research questions (RQs):

- **RQ1***: How can MoDRE techniques support communication with stakeholders involved in the representation of a process transformation in agricultural contexts?* To answer RQ1, we propose a method based on graphical models from the MoDRE field and a procedure for data collection based on a reporting template. In selecting the models we consider prominent notations for the representation of social interactions and goals, system components, and processes, and we plan to adapt the notations to maximise usefulness and understandability to stakeholders with no expertise in the notations.
- **RQ2***: Can the method be applied to real agricultural contexts?* To answer RQ2, we intend to assess the method developed in RQ1 through action research [25]. We plan to apply the method to 20 European LLs from the CODECS project. LLs are characterised by different technologies, expertise and levels of introduction of the technological solution; this will allow us to refine the method through interaction with different contexts.
- **RQ3***: How to make end-users autonomous in the representation of systems and processes without knowing formal languages?* To answer RQ3, we propose the development of a web tool accessible to LLs to support end-users in process modelling to be included in the method developed in RQ1. The tool is conceived as a single-software web environment for requirements elicitation based on an intuitive visual language that can be exported into standard code.

4. Research Plan

The development of this PhD research can be summarised into consecutive steps corresponding to the steps of the design science process, according to Johannesson et al. [8].

- Step 1 — *Problem explication.* The research started with an analysis of the general problems declared by stakeholders of CODECS and was consolidated with a literature review. This led to the three RQs presented in 3.
- Step 2 — *Requirements definition.* In this phase, we started to address RQ1 through the sub-steps of artefact outline and requirements elicitation. A draft of the artefact was preliminarily evaluated with representatives of the LLs through a case study. This led to the definition of the method

composed of a set of diagrams, a procedure based on a reporting template and the tool for end-users; this will be presented more in detail in 5. A list of requirements is currently under refinement. In parallel, a prototype of a modelling tool for end-users addressing RQ3 is being developed and was preliminarily evaluated through a walkthrough with experts.

- Step 3 — *Artefact design and development.* The outlined artefact has been further developed following the evaluation carried out in the previous step and a second case study was conducted in the context of a LL from CODECS, serving as a pilot study for the project. This led to an improved version of the diagrams and to the procedure for data collection to be followed by LLs.
- Step 4 — *Artefact demonstration.* In this phase we address RQ2 through the application of the method to the LLs of CODECS. Following action research, we plan to perform the data collection in the next months and then proceed with the development of the diagrams through several iterations with LLs. In the final phase, we plan to perform a validation of the diagrams with LLs.
- Step 5 — *Artefact evaluation.* We plan to perform this step once the demonstration is completed through a validation of the entire method with LL coordinators. To ensure that the representations produced and the procedure followed are useful and understandable, we will evaluate them according to the Technology Acceptance Model (TAM) [26].

5. Proposed Solution and Preliminary Results

In this PhD research, we propose a method based on MoDRE to represent the process transformation after the introduction of digital technologies in agricultural contexts. With the models, we aim to describe all the elements of interest related to a process of transformation occurring after the introduction of a digital technology within a socio-technical system, i.e. a system characterised by a relevant social component. We call our method *socio-technical process modelling*. The transformation is emphasized by qualitatively highlighting the differences in the process-*as-is* (before) and the process-*to-be* (after).

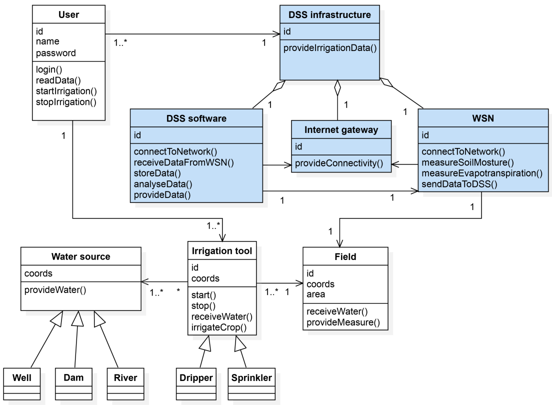
The method is composed of (1) a set of diagrams, (2) a procedure based on a template for data collection within LLs, and (3) a tool to support end-users in the creation of the models. The method will be applied and evaluated within the 20 LLs of CODECS.

The set of diagrams. To ensure completeness, the representation of a process transformation focuses on three complementary dimensions, i.e. structure, goal and process. This can be represented through a set of different diagrams:

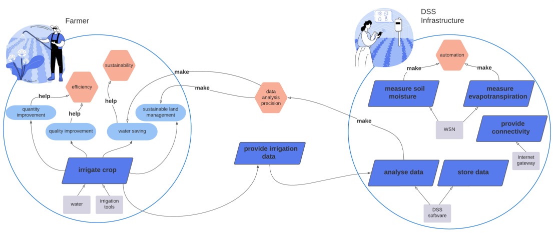
- *Structure*: the UML class diagram provides an overview of the process structure, i.e. actors, resources, tools, and infrastructures involved in the process-to-be and their relationships [27]. In this representation, the new classes introduced by digital technology are in light blue. (Fig. 1a).
- *Goal*: the i* diagram models the goals of the process-to-be focusing on the intentional, social, and strategic dimensions [13]. For this type of diagram, we propose to adopt 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. 1b).
- *Process*: the BPMN diagram [16] 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 and after the introduction of the digital technology (Fig. 1c).

The selection of models is based both on the literature review and the evaluation with stakeholders.

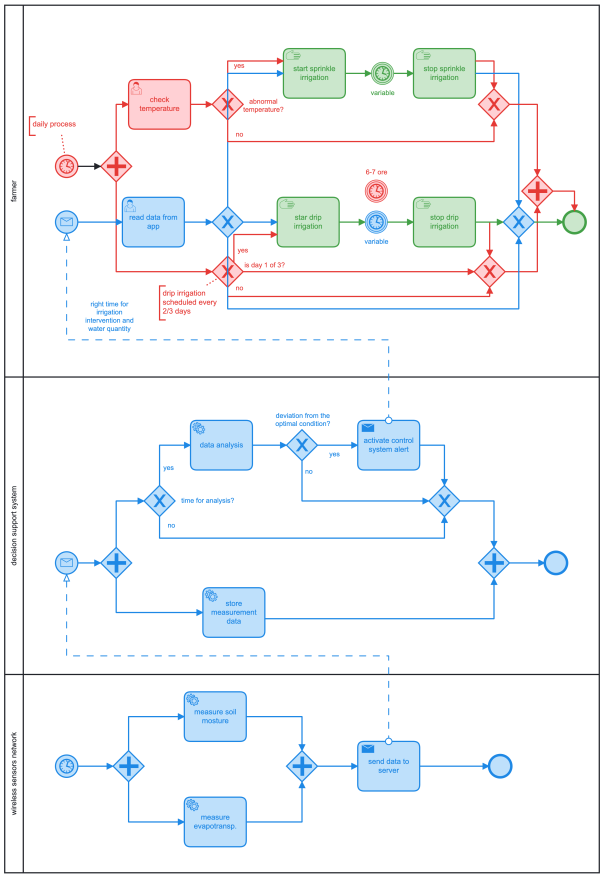
The procedure for data collection. To perform data collection, we propose a procedure based on guidelines and a reporting template to be filled by LL coordinators. The procedure is meant to support the elicitation of information from multiple stakeholders through workshops and focus groups. According to this procedure, the reporting template will contain all the data necessary for the creation of the diagrams that will be developed and syntactically validated by experts in the notations.



(a) UML class diagram



(b) i* goal diagram



(c) comparison of BPMN process diagrams

Figure 1: Models representing an irrigation process transformed by the introduction of a precision irrigation system

The tool for end-users. In addition, a tool enabling end-users to create the models is being developed. The tool has a double objective: to speed up the process of creation of multiple diagrams through a single web interface and to allow users with no expertise in the notations to edit and create the diagrams. A prototype version of the tool has been released and is presented in [28].

Case studies. The development of the method is being carried out iteratively. The process started with the development of a draft of the artefact and a preliminary assessment through two case studies (CS) which were collectively evaluated by a group of selected stakeholders, including both experts in the notations and domain experts.

- **CS1**: is based on a smart irrigation system adopted on a pear orchard by a fruit farm[2] in Tuscany. A precision irrigation system, composed of a wireless sensor network (WSN) and a decision support system (DSS), has promising potential in terms of economic, productive, and environmental benefits. The diagrams are presented in 1.
- **CS2**: is the pilot study carried out with *Pecorino Toscano*, a LL from CODECS, based in Manciano, Tuscany and focused on the activity of sheep breeding and pecorino cheese production. The LL is built around the development and evaluation of a farm management information system (FMIS) aimed at supporting interoperability among several on-field technologies and a mobile application to monitor animals' health status, food ratios and milk production.

The evaluation carried out in the CSs allowed us to refine the representations and collect requirements for the procedure for data collection in LLs. A preliminary version of the proposed method and the two case studies are presented in [29, 30].

[2]http://www.illuminatifrutta.it *last visited 7 February 2024*

6. Conclusions and Future Challenges

In this PhD research, we address the challenge of modelling process transformation in the domain of digital agriculture. We propose a method based on MoDRE that includes a set of diagrams, i.e., UML class diagrams, i* and BPMN, a procedure to carry out data collection and a tool for end-users. We preliminarily evaluated the diagrams through two case studies in precision irrigation and cheese production, and the preliminary results confirm the feasibility of the proposal. At the current state, the TAM-based evaluation of the models has not yet been performed. However, we plan to 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 [31]. For clarity's sake, we provide three examples of questions we plan to ask for PEOU, PU, and ITU respectively: 1) It was easy for me to understand what the models meant and the steps of the procedure; 2) Overall, I think that the modelling procedure provides an effective means for evaluating the process transformation and its impact; 3) If I were to evaluate a process transformation and its impact, I would adopt this modelling procedure.

The main challenge ahead consists of the demonstration of the artefact with the application of the method to 20 LLs. This step will allow us to evaluate the effectiveness of the method within real agricultural contexts which are characterised by diverse needs, skills and levels of digitalisation. This will contribute to filling the lack of empirical evidence on the applicability of MoDRE techniques to real-world contexts with a relevant social component, as evidenced in the previous section. At the same time, the feedback received from LLs will allow us to fine-tune the method. Moreover, new research challenges arise from the tool for end-users, as proposed in RQ3. A first challenge is related to the creation of the tool which requires the development of a new user-friendly approach for the formalisation of the diagrams based on the selected notations. A second challenge is related to the evaluation of the tool through case studies to be performed in LLs.

Acknowledgments

This work has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement no. 101060179.

References

[1] K. Rijswijk, L. Klerkx, M. Bacco, F. Bartolini, E. Bulten, L. Debruyne, J. Dessein, I. Scotti, G. Brunori, Digital Transformation of Agriculture and Rural Areas: a Socio-Cyber-Physical System Framework to Support Responsibilisation, JRS 85 (2021).

[2] A. Ferrari, M. Bacco, K. Gaber, A. Jedlitschka, S. Hess, J. Kaipainen, P. Koltsida, E. Toli, G. Brunori, Drivers, Barriers and Impacts of Digitalisation in Rural Areas from the Viewpoint of Experts, Information and Software Technology 145 (2022).

[3] M. Hossain, S. Leminen, M. Westerlund, A systematic review of living lab literature, JCP 213 (2019).

[4] S. Assar, Model driven requirements engineering: Mapping the field and beyond, in: 2014 IEEE MoDRE, 2014.

[5] D. Moody, The "physics" of notations: Toward a scientific basis for constructing visual notations in software engineering, IEEE Transactions on Software Engineering 35 (2009).

[6] A. Mavin, P. Wilkinson, S. Teufl, H. Femmer, J. Eckhardt, J. Mund, Does goal-oriented requirements engineering achieve its goal?, in: 2017 IEEE 25th International Requirements Engineering Conference (RE), 2017.

[7] J. Doerr, A. Hess, M. Koch, Re and society-a perspective on re in times of smart cities and smart rural areas, in: RE'18, IEEE, 2018.

[8] P. Johannesson, E. Perjons, An Introduction to Design Science, Springer International Publishing, Cham, Switzerland, 2014.

[9] H. Ye, Y. Wang, Y. Zhang, X. Hu, C. Wei, W. Zhao, X. Li, Digital transformation of agriculture: A new integrated modeling framework for arable farm enterprises, Computers and Electronics in Agriculture 212 (2023).

[10] W. Purcell, T. Neubauer, Digital twins in agriculture: A state-of-the-art review, Smart Agricultural Technology 3 (2023).

[11] C. Pylianidis, S. Osinga, I. N. Athanasiadis, Introducing digital twins to agriculture, Computers and Electronics in Agriculture 184 (2021).

[12] J. Horkoff, F. B. Aydemir, E. Cardoso, T. Li, A. Maté, E. Paja, M. Salnitri, L. Piras, J. Mylopoulos, P. Giorgini, Goal-oriented requirements engineering: An extended systematic mapping study, Requir. Eng. 24 (2019).

[13] E. Yu, P. Giorgini, N. Maiden, J. Mylopoulos, S. Fickas, Social Modeling for Requirements Engineering, The MIT Press, 2011.

[14] A. Siena, N. Maiden, J. Lockerbie, I. K. Pitts, A. Perini, A. Susi, Exploring the effectiveness of normative i* modelling: Results from a case study on food chain traceability, 2008.

[15] M. Ruiz, D. Costal, S. España, X. Franch, Óscar Pastor, Gobis: An integrated framework to analyse the goal and business process perspectives in information systems, IS (2015).

[16] Business process model and notation (BPMN) v2.0, https://www.omg.org/spec/BPMN/2.0/, 2010. Version 2 | Online; accessed 9-February-2023.

[17] F. Corradini, A. Ferrari, F. Fornari, S. Gnesi, A. Polini, B. Re, G. O. Spagnolo, A Guidelines framework for understandable BPMN models, Data & Knowledge Engineering 113 (2018).

[18] W. Van Der Aalst, Process mining: discovery, conformance and enhancement of business processes, volume 2, Springer, 2011.

[19] K. A. Alam, R. Ahmad, A. Akhunzada, M. H. N. M. Nasir, S. U. Khan, Impact analysis and change propagation in service-oriented enterprises: A systematic review, IS (2015).

[20] Y. C. Law, W. Wehrt, S. Sonnentag, B. Weyers, Obtaining semi-formal models from qualitative data: From interviews into bpmn models in user-centered design processes, International Journal of Human–Computer Interaction 39 (2023).

[21] M. Prilla, M. Schermann, T. Herrmann, H. Krcmar, Process Modeling with SeeMe: A Modeling Method for Service Processes, Gabler Verlag, Wiesbaden, 2012.

[22] U. Kacmaz, T. Herrmann, M. Jelonek, Seeme2bpmn: Extending the socio-technical walkthrough with bpmn, in: HIMI 2020 IN HCII 2020, Proceedings, Part I, Springer-Verlag, Berlin, Heidelberg, 2020.

[23] M. Modiriasari, T. Herrmann, Seeme* - a process modelling notation for socio-technical requirements-engineering, in: STPIS, 2022.

[24] M. Host, A. Rainer, P. Runeson, B. Regnell, Case study research in software engineering: Guidelines and examples, John Wiley & Sons, 2012.

[25] P. Runeson, M. Höst, Guidelines for conducting and reporting case study research in software engineering, Empirical software engineering 14 (2009) 131–164.

[26] F. D. Davis, Perceived usefulness, perceived ease of use, and user acceptance of information technology, MIS quarterly (1989).

[27] Unified modeling language (UML) 2.5.1 core specification, https://www.omg.org/spec/UML, 2017. Version 2 | Online; accessed 14-September-2023.

[28] C. Mannari, E. Anichini, M. Bacco, A. Ferrari, T. Turchi, A. Malizia, Modeller – a prototype to support requirements elicitation in co-design environments, 2024.

[29] C. Mannari, G. O. Spagnolo, M. Bacco, A. Malizia, Digitalisation of agriculture: Development and evaluation of a model-based requirements engineering process, in: REFSQ 2023 - Posters and Tools, 2023.

[30] C. Mannari, M. Bacco, A. Ferrari, L. Ortolani, M. B. Lai, C. Mignani, A. Silvi, A. Malizia, G. Brunori, A methodology for process modelling in living labs to foster agricultural digitalisation, in: 2023 IEEE MetroAgriFor, 2023.

[31] S. Abrahão, E. Insfran, J. A. Carsí, M. Genero, Evaluating requirements modeling methods based on user perceptions: A family of experiments, Information Sciences 181 (2011).