Cultivating Sociomaterial Transformations in Agriculture 4.0: The Case of Precision Viticulture

Completed Research

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Abstract

Agriculture 4.0 is a growing field of research that aims to solve one of the most critical challenges for humanity: efficient production in a changing environment. This paper presents a two-year long research project in a wine producer with over 800 associates. The results provide an in-depth presentation of transformations in two vineyards using a ubiquitous system supported by smart sensors, machine-learning, and augmented reality. It also highlights the importance of preparing a sustainable strategy that includes (1) a farmer-centered design of agriculture 4.0, (2) an ecosystem of third-party entities that ensure co-evolution with the producer, and (3) the added value of an increasing amount of data. Failing to achieve these recommendations may lead to a decrease in long-term adherence to digital transformation. The findings are relevant for companies that struggle worldwide with extreme threats of climate change and to maximize the return of their investments in agriculture 4.0.

Keywords

Viticulture 4.0, sociomaterial transformation, ubiquitous systems, smart sensors, augmented reality.

Introduction

Digital transformation is affecting all sectors of the economy. As stated by Klaus Schwab, the founder and executive chairman of the World Economic Forum "*we are in the midst of the Fourth Industrial Revolution* [alias Industry 4.0]*, which will affect governments, businesses and economies in very substantial ways. We should not underestimate the change ahead of us*" (Schwab 2015). This *revolution* is now reaching traditional sectors of the economy, namely with agriculture 4.0, supported by technologies such as RFID (radio frequency identification) and smart sensors to face one of the biggest challenges of humanity: food production. However, it is surprising that in spite of the scientific advances and numerous pilot projects, managers still see "modest returns" in agriculture 4.0 (Weltzien 2016).

Precision viticulture is one paradigmatic example of digital transformation with the use of remote monitoring systems (Spachos and Gregori 2019). But, as concluded by Matese and Di Gennaro (2015), technology is only one aspect to consider in the smart farm. The ongoing transformation depends on (1) the farmers knowledge and adherence to the new systems available, (2) the entrepreneurs' ability to bring academic pilot projects to the market and ensure respective system maintenance and continuous improvement, (3) the optimization of plant selection and growth, and (4) the improvements in energy consumption and environmental impact.

Digital transformation raises new forms of relations between human and non-human elements in agricultural practices. In fact, "*technology is an integral part of the fact of work and its performance in the world*" (Orlikowski and Scott 2008). However, the relations between humans and different forms of materiality (Yoo 2010) in agriculture, either physical (e.g. plants, farm, equipment) or digital (e.g. software platforms, mobile apps) did not yet receive sufficient attention in the information systems (IS) extant literature. Moreover, there is an urgent need to increase productivity to deal with the constant growth of population, climate change, and ensure careful use of natural resources.

Wine production is the most important areas of the primary sector in Portugal. It reached close to 6 million hectoliters in 2016 (2.3% of the world production) and accounted for exports of about 783 million euro, ranking 5th in Europe and 10th in the global rankings (Rebelo et al. 2019). Important and valuable as it is, wine production depends on diverse unmanageable factors (e.g., climate conditions and plagues) and in thorough monitoring, which makes it a prime candidate for the use of precision agriculture techniques (Popović et al. 2017). Our research started when a major wine production cooperative in the region of Bairrada, Portugal, decided to lead a project – *Inovwine* – aimed at increasing the quality of its wines, namely the younger ones that constitute the biggest share of the revenue. Their dual aim of boosting productivity and quality via digital transformation created the context for our two year-long action research project (Baskerville and Wood-Harper 1996; McKay and Marshall 2001). It was partially supported by the European Union and lead to the following research questions:

- *How should the wine producers improve their work practices intermediated by digital artefacts?*
- *How can technologies change vine selection, development, and quality in agriculture 4.0?*

The remainder of our paper is organized as follows: next, we uncover background literature on agriculture 4.0 and sociomateriality. Then, we justify the option for action research and describe the context for field intervention. In the next section, the results are presented, followed by the discussion, and research implications. Subsequently, we suggest opportunities for future avenues of work. The paper closes with the conclusions and study limitations.

Theoretical Background

Digital Transformation in Agriculture

The term "agriculture 4.0" is still emerging in the literature and refers to the adoption of digital technologies, for example, smart sensors, cyber-physical systems, or augmented reality (Weltzien 2016). It is deeply intertwined with the concepts of digital agriculture and precision agriculture, aiming at the increase of production and sustainability of resources (Yost et al. 2019).

The applications of new technologies in viticulture are vast. The study presented by Matese and Di Gennaro (2015) provides a comprehensive view of key functionalities adopting robotics, drones, and mobile platforms, for example, vehicle safety and movement with geolocation, crop monitoring with Global Positioning Service (GPS), and soil quality monitoring. The authors conclude that remote sensoring is now stable but that other types of technologies are still at the prototype stage. They also state that there are issues to address before a widespread adoption of these technologies, "*which are related not only to the need to further explore the potential of these tools, but above all to the ability of farms to train technicians capable to understand and properly use this type of technology*" (Matese and Di Gennaro 2015).

Precision viticulture refers to the adoption of management practices that depend on the site conditions, which can be achieved by the use of wireless sensor networks (WSNs) that allow remote sensing (Ananda and Paramasivam 2018; Matese et al. 2009; Morais et al. 2008). The interest for sensoring the vines is well justified by the growing wine market and the need to increase production in unpredictable environmental conditions (Rebelo et al. 2019). Other technologies have not received the same attention as WSNs, but the interest in them is increasing, for example, the use of drones and augmented reality presented by Huuskonen and Oksanen (2018). Nevertheless, there is a gap in contributions that focus on the users of the technology in their daily processes. Moreover, we could not find studies that report on the adoption of large-scale applications in viticulture supply chains.

The "social" side of agriculture 4.0 is understudied when compared to the technology focus. The extension of the fourth industrial revolution to agriculture offers many opportunities to improve the farmers work and the end-to-end digital integration in supply chains, which is a priority in industry transformations. Yet, "*the uptake of new technologies in farming remains below expectations* [and…] *will be accelerated by creating a framework in which farmers, cooperatives, extension professionals, scientists and the private sector can effectively collaborate and co-create knowledge*" (Bucci et al. 2018). Additional research is needed that explores the sustainability of smart farming solutions.

Sociomateriality Theory

Sociomateriality is gaining popularity in IS since 2007, with a *strong* variant affirming that reality only exists in the intra-actions between entities, and a *weak* version that concentrates on the stability of arrangements of materials, not rejecting its preexisting forms, attributes and capabilities. Orlikowski and Baroudi (1991) argue that the social and the material are inseparable and entangled, while other researchers support the vision that it is possible to consider them apart in IS research, for example using the concept of "*imbrication – the gradual overlapping and interlocking of distinct elements into a durable infrastructure*" (Leonardi 2013).

It can be argued that the sociomaterial is inborn to IS studies that address the social and material (e.g. IT) transformations. Some authors suggested that more researchers and practitioners need to apply the sociomateriality lens in design (Hylving 2017; Leonardi and Rodriguez-Lluesma 2013). According to Hylving (2017), "*designers should create a practice that enables possibilities for experiences rather than trying to predefine and control a design so it fits a plan*".

The lens of sociomateriality is particularly useful in agriculture 4.0, which aims at introducing changes in production technologies and practices in an integrated way (Hallin et al. 2017). Both, the sociomateriality theory and the action research literature consider that knowledge is created through intervention in the real world (Leonardi 2013; McKay and Marshall 2001). Therefore, it offers an opportunity to evaluate how the social and the material evolve in an integrated way to form a "durable infrastructure" in agriculture 4.0.

Methodology

This work has a dual goal of assisting a leading wine producer in its digitalization and contributing to the understanding of transformations in agriculture 4.0. Therefore, action research was selected, which is "*one of the few research approaches that we can legitimately employ to study the effects of specific alterations in systems development methodologies in human organizations*" (Baskerville and Wood-Harper 1996). Action research evolves iteratively, starting with a diagnosis of the situation. Then, researchers and practitioners cooperate in cycles of problem solving and research, evaluating the consequences of actions taken and documenting the outcomes (McKay and Marshall 2001). Our research resorts to sociomateriality theory (Orlikowski 1992) as the focal theory (Davison et al. 2012) to evaluate the case evolution and propose a transformation strategy.

Context of the Research

The wine production cooperative counts around 800 associates and is the largest player in the region, at approximately 25 to 30% of the total production. The project budget was approximately 823.000€ and it addressed key activities in the wine production value chain, namely:

- Ensuring the quality and certification of the grapevines to be planted in the vineyards. To this end, a genotyping system based on molecular methods was created, to obtain the exact identification of the grapevine genetics. These credentials are recorded into RFID tags implanted in the plants during the grafting at the grapevine nurseries. This process provides assurances regarding the legitimacy of grapevine variety at the moment of plantation, and later allows producers to trace the history of each grapevine (e.g. production, diseases) throughout its lifetime;
- Identifying specific wine yeasts that can potentiate the regional grapevine varieties and ways to monitor their dynamics during fermentation. The use of local, custom, yeasts instead of generic ones enables the production of better wines, in line with the characteristics demanded by the market;
- Improving the effectiveness of the care of the vineyard, by systematically controlling its characteristics and evolution, as well as a set of biotic (e.g. living organisms, such as virus) and abiotic parameters (non-living chemical and physical factors in the environment such as light, temperature, water, and soil).

Action Planning

The case company partnered with a biotechnology lab and a technology transfer organization. A vineyard nursery, that provides certified grapevines, was also enrolled. The reported research has involved two PhD researchers, one PhD student, and five developers for a period of two years. Data collection included interviews, observation, and document collection that was audited by the project supporters. Research started with a literature review that was useful to frame the problem space and propose an action plan. Progress reports were provided to the vineyard cooperative and regular meetings took place to plan actions.

The vision for the project was, thus, to build a system capable of transforming data coming from sensors placed in the vineyards and data entered by the producer during the care (manually or via RFID) into actionable advice regarding plantation, treatments, watering, and management. Proper processing of this mix of historical and real-time data has the potential to originate specific guidance, such as, for example, anticipating, postponing, or even foregoing chemical treatments according to environmental conditions and their influence on the probability of occurrence of specific plagues.

The vineyard cooperative was aware of the opportunities for digitalization in agriculture (Lehmann et al. 2012) but the majority of studies addressed specific implementations such as mobile systems (Cunha et al. 2010), drones (Huuskonen and Oksanen 2018), or Internet-of-Things (Ray 2017), lacking studies that integrate the complex socio-technical scenario of a cooperative information system with hundreds of associates. Moreover, most proposals were "*not adequate as per the technical capabilities of farmers* [...] *the interfaces of these systems were complex* [...] *were hardware centered and maintenance feature of these systems was highly ignored in system design* [and...] *most of these systems are used by agricultural researchers and experts for research purposes* [... compromising its use] *in more than one field*" (Kamran et al. 2016). The cooperative was interested in creating a sustainable investment in agriculture 4.0 that could inspire the entire wine cluster in the Euroregion. The next section presents the field intervention.

Results from the Field: Farm Digitalization in Large Scale Vineyards

The work started with the development of a real-time control system for the field and vines, including (1) sensors to acquire information in real-time, (2) an intelligent software to evaluate vineyard management against a desired performance, and (3) actuators. Sensoring is performed at three distinct levels: a wireless sensor network spread out in the terrain, smartphone sensors such as GPS, RFID reader, and a digital compass, and the farmers input in the smartphone as a result of his/her observations. The intelligent software comprises a machine-learning component that is loaded with data from previous viticulture campaigns to generate a predictive model of the conditions for occurrence of pathologies in the vineyard, thus helping the farmer in deciding when to intervene (e.g. watering, treatments) with the goal of increasing production and/or the quality of the final product. An alarm generator issues warnings and advice to the farmers' smartphone. Figure 1 represents the technical architecture of the proposed solution.

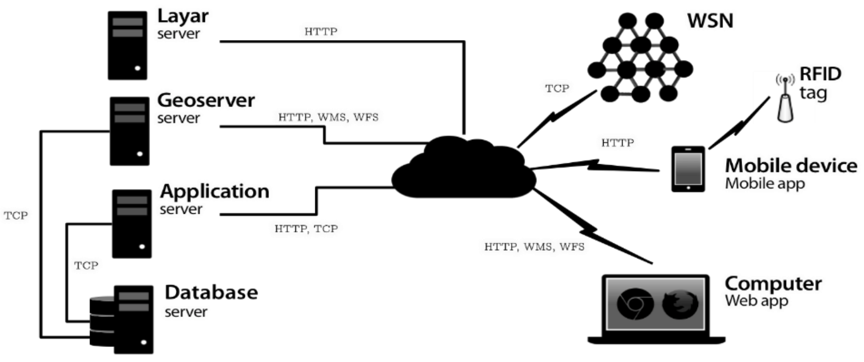


Figure 1. Digital architecture of the precision viticulture system.

The infrastructure comprises the WSN, the Backoffice (web app), and a mobile application. It integrates a PostgreSQL database with PostGIS – a plugin that adds support for geographic objects – and GeoServer, an open source software server that allows sharing geospatial data – for back office application – through the services Web Map Service (WMS) and Web Feature Service (WFS). The WSN (top-right of the figure) consists of three main modules, namely the gateway, the end nodes, and router nodes. The WSN gateway aggregates abiotic data, ensuring their authenticity. Additionally, it uploads that data to the system's Backoffice. The mobile application augmented reality feature uses Layar service/mobile application (http://www.layar.com/). It communicates with its service to retrieve the vineyard layer with points of interest (network nodes and alerts) related with current farmer location. The Layar service is responsible for making requests to the Backoffice interface to collect information about the area surrounding the coordinates sent by mobile application. The mobile device uses GPS to retrieve user location and the mobile application reads information related with the RFID tag placed in the vineyard.

The objective of using RFID technology is the unambiguous identification of the vines, due to the geographical points perfectly identified in vineyard, when associated with a GPS location. A total of 109 RFID tags were installed (40 in adult vines and 69 in vines grafts). The conditions were controlled to ensure a minimum ratio of 1:1 between identified plants and plants with similar characteristics. Moreover, the physiological response of the vines was monitored after the insertion of RFID tags with the following parameters: evolution of phenological state, evaluation of physiological functions of the vine sprouting index, fertility rates, size of the wattle, number of leaf layers and leaf area. The results obtained show that in the first year of the RFID tag deployment, communication between the RFID reader and the tags remained fully functional without any detected attenuation. The tags also did not cause significant changes in the physiology of the vine.

The WSN comprises a gateway associated to a set of 50 nodes, between router and end nodes. Each node consists of a central processing unit, a radio, a flash memory, a battery pack, and digital and analogue interfaces. Routers and gateway nodes include a solar recharging batteries module, in order to extend the autonomy. In comparison with automatic weather stations, the WSN increases the precision of the collected data and provides a detection tool for microclimates. Each node also has an associated sensor pack for: air temperature, air humidity, leaf wetness, soil moisture, solar radiation, UV radiation, air pressure, wind speed, wind direction, and rainfall. The data transmission between nodes and the gateway is based on ZigBee protocol (Morais et al. 2008) and is performed under a cluster-tree topology (left of Figure 2). If a node fails, the system recombines the connections in order to maintain the operability of most nodes.

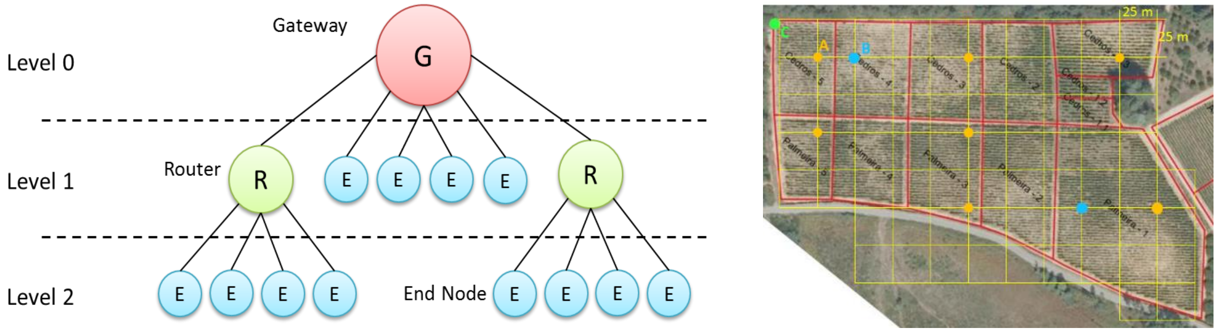
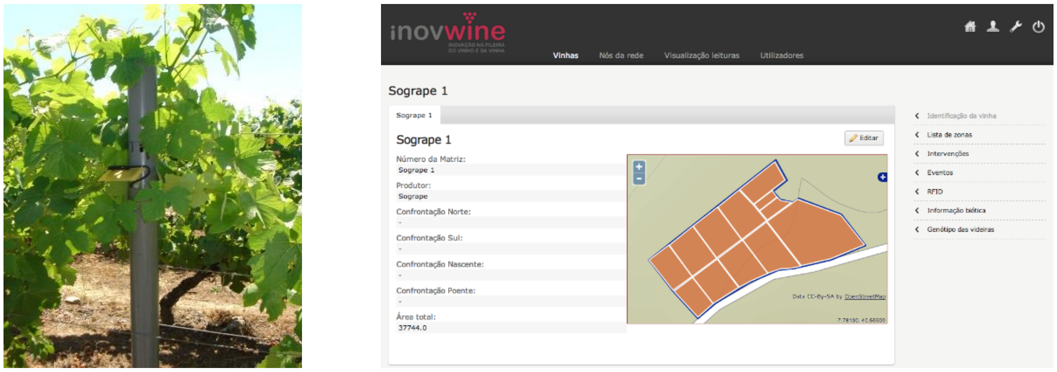


Figure 2. WSN typology and installation matrix.

A scalable network was developed to cover large areas, with self-healing algorithms and large autonomy. The first WSN was installed in the first year of the project, in a vineyard with about 5 ha, using 7 end nodes, 2 routers and the gateway (in a total of 10 nodes). Figure 2 includes the WSN typology developed for large scale implementations and a satellite picture (on the right) with the division made on vineyard plots in the matrix (grid side of 25 m). Figure 3 presents an end node (left) and the web interface (right).



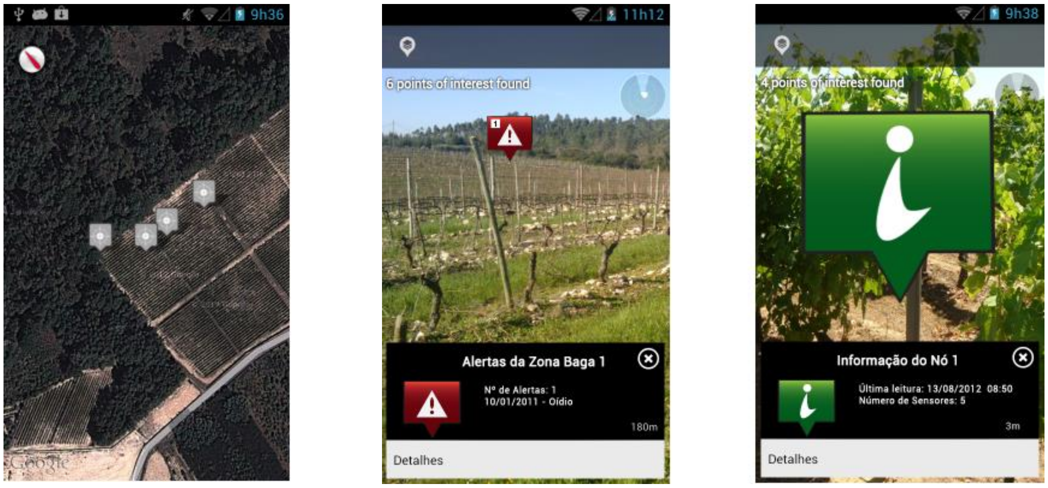
Sogrape 1

Sogrape 1

Número da Matriz: Sogrape 1
Produtor: Sogrape
Confrontação Norte: -
Confrontação Sul: -
Confrontação Nascente: -
Confrontação Poente: -
Área total: 37744.0

Figure 3. WSN end node and web interface.

Smartphones have an important role in this system: as sensors for the real-time control system, making use of built-in sensors and by asking data from the farmer, as actuators in the sense that they expose the farmer to instructions for actions in the field (here called alarms), and as a ubiquitous dashboard. The smartphone connects various elements in the vineyard: the farmer, the digital space, and the physical space (vineyard and WSN), generating a computational representation to the farmer (alarms, visualizations, notepad, and task manager) and geo-tagging the various physical elements in the field. Figure 4 presents three examples of augmented reality use in the vineyard.



Alertas da Zona Baga 1
Nº de Alertas: 1
10/01/2011 - Oídio

Informação do Nó 1
Última leitura: 13/08/2012 08:50
Número de Sensores: 5

Figure 4. Taking advantage of augmented reality in the farm.

The example presented in Figure 4 includes the field visualization using GPS information (on the left) an alarm of plant disease (on the middle) and the information interface of a specific plant (rightmost image). By touching the icons, the user can check the content of the point of interest: a description of the alert or the values of the sensors. The smartphone also acts as a proxy of the user, constructing a representation of the farmer's daily routines, behavior, and preferences to feed the machine-learning component. The wireless sensor network and smartphones carried by the farmers are used to feed data to the machine-learning component of the system, providing information on events that occurred in the vineyard, such as the appearance of a disease or the change in maturity state of the grapes, as well as information about interventions performed by the farmer, such as pruning of the vineyard. A photo can also be sent with the data for later analysis. All the alarms are geo-referenced allowing the farmer to locate the problematic areas and act accordingly. The system analyzes received data according to a set of pre-defined rules (e.g. IF "Rain > 20mm" AFTER "phytosanitary treatment" THEN "Risk of washing") and generates alerts accordingly. Other examples of relevant alerts are related with annual/daily extreme values like maximum/minimum temperature, maximum precipitation in 24 hours or maximum number of days without rain.

Discussion

Our research is interested in the world of practice and the relevance of IS research for societal changes of our era (Avison et al. 2018). The action previously presented is only one part of the equation in action research, fostering a continuous reflection and learning in joint colaboration with the pratitioners (McKay and Marshall 2001). According to the sociomateriality theory (Orlikowski and Scott 2008), it is not possible to understand the practices or the material - physical or digital (Yoo 2010), in isolation. In the reported case, changes introduced by new wireless sensor technologies had a significant effect in the entire agriculture context, including the vines, the environment, the cooperative, and the farmer. To be sustainable, technological transformations must also become entangled with the social practices.

The possibility to introduce sensors in vineyards is now acessible and the technological portfolio is vast (Matese et al. 2009). However, we found that the field interaction between the farmer and the vines, directly, via the mobile phone and the augmented reality app is crucial. The mere adoption of sensors for monitoring and decision support presents risks for the sustainability of this type investment. One possible reason is the need for direct contact with the crops by the farmers. If the system does not assist the interaction in daily practices, it is possible that the project will remain at an experimental level – a risk identified in the literature (Kamran et al. 2016). Altough the data gathered by the sensors is valuable for alerts and logs, the farmer may consider it a mere offline support system and not interact with the app in real-time. According to the cooperative, the project goals were achieved, going beyond the mere "real-time" control, thus minimizing the risk of abandonement. Product certification requires that farmers interact with the system continuously, not merely to evaluate historical data or an instant messaging system.

Each actor has different interests that must be balanced with the "*digitally mediated everyday experiences*" (Yoo 2010). While the farmer found the most interesting funtionalities in the smartphone app and the augmented reality solution, the priority for the cooperative is the certification of grapevines and the potentiation of the regional grapevine varieties. There are other relevant social elements of the vineyard ecosystem: research institutions and technology providers. Data is critical to understand plant desease and treatment effectiveness. Altough the data collected by the sensors also had the purpose of scientific analysis since the early phases (with the participation of a biotechnology partner), it is recommended that wine producers consider the data collected by real-time systems and their own manual inputs as valuable assets for science. Precision vineyard requires a strategy for optimizing each plant, requiring advanced knowledge and research, not limited by operational support systems (e.g. for alerts) or decision support systems (e.g. to identify irrigation needs). Data is of common interest for different partners of the ecossystem.

Our work extends the body of knowledge in agriculture 4.0 that presents the vast potential of Internet-of-Things (Popović et al. 2017). Other authors, for example, Matese and Di Gennaro (2015), already pointed to social issues "*which are related not only to the need to further explore the potential of these tools, but above all to the ability of farms to train technicians capable to understand and properly use this type of technology*". Our work reveals the importance of other stakeholders in the supply chain and the analysis of the material as inseparable from practices (Orlikowski and Baroudi 1991) in agriculture. The entanglement in social and material realms is key to reinforce the sustainability of the solution, contributing to overcome the well-known problems of poor return on investment and the need to promote the adherence of the user to digital transformation (Weltzien 2016; Yost et al. 2019). This observation, although already well-known in the IS field, has not been fully explored in agriculture 4.0 as we discuss in the study implications for theory and for practice.

Implications

Implications for Research

Sociomateriality theory (Orlikowski and Baroudi 1991) is a valuable lens to understand transformation processes in traditional sectors of the economy. We also confirmed that it is important for the design of agriculture 4.0. Contrary to pilot projects that aim to test or evaluate technologies, a large-scale investment must consider the integration of social and material elements. The "social" in our case includes the users of the technology and many other stakeholders interested in (1) the data, (2) the vines for wine production, (3) the final consumer, (4) the IT companies that will ensure project sustainability. Despite the growing research in precision viticulture, there is a lack of studies that include multiple technologies to reach the most ambitious goal: sustainably transform agriculture. To be successful, agriculture 4.0 must be seen as a deep transformation of social and material arrangements to face societal impacts and promote organizational competitiveness. We identified relevant entanglements in our case, for example, the integration of the vine, the RFID tag, and the augmented reality app that supported the farmer. Moreover, the environmental conditions are evaluated by the machine-learning component of the system to improve our knowledge about farming productivity and selection of the best products. During one year, our team did not found relevant risks to the vines (e.g. growht rate or quality) with the nearby use of sensors. Yet, if this type of systems become the standard in agriculture, additional efforts must be made to evaluate its long-term impacts, and to prevent intentional damages to the equipment and oportunities for stealing. Incorporating cameras in the vine plantation and using drones are possible solutions to explore.

Implications for Practice

Our study reveals two major challenges for managers, namely to (1) ensure the sustainability of the investment with a network of competences in the supply chain, and (2) explore data beyhond the mere use for historical data and alarms.

The system sustainability is only possible if third party entities become empowered to proceed with the digital platforms and explore its market value. Agriculture 4.0 can't be supported exclusively by experiments and pilots. The project that we report in this paper includes a number of hardware and software elements that will require maintenance, changes, and improvements. Moreover, large scale projects have additonal requirements that pilot projects miss, for example, the architecture required to achieve (1) resilience in physical (e.g. vines, sensors) and digital (e.g. apps) materialities and (2) farmer adherence. The transition of academic pilot studies to industry implementations demands considerable effort. It is necessary to create an ecosystem that provides the required maintenance and evolution of the digital infrastructure. Our findings suggest that managers should seek cooperation with technology transfer institutions to ensure a comprehensive network of competences: agriculture, technology, and entrepreneurship. We recommend that pilot projects should be deployed to assist in the formulation of the large scale implementation strategy and not merely to test if a specific technology works.

It is dificult to justify major investments in agriculture 4.0 just for the possibility of having real-time alerts and sensor data. The return of investment in this scenario is likely to remain modest and discourage the industry, most probably because social practices in agriculture are based in close contact with the farm. Therefore, viticulture managers must raise the ambition to diferentiate their products with the power of data and transform work practices intermediated by technology. This type of feedback requires a rules engine and machine-learning techniques to create distinctive value with data. Smart glasses were not considered aplicable for daily use in this case (at least in the current stage of development of this products) – it would be a burden to the farmer, when smartphones are already used nowadays. Our results also suggest that large scale viticulture implementations can capture the attention from academic partners, consequently, improving the possibilities to differentiate even more the final product.

Future Research Directions

First, while the technological infrastructure for descriptive and diagnostic analytics is stable and detailed in the literature and already advanced in countries like United States and Australia (Nolet 2018), the user adherence to new technologies in traditional sectors such as agriculture is scarcely studied. Moreover, precision viticulture requires additional research for predictive analytics (integration of multiple data sources as we report in this case) and prescriptive analytics that take advantage of artificial intelligence.

Second, ubiquitous systems as we described can contribute to transparency in food supply chains and increase trust in product certification (Wognum et al. 2011). An example is the use of collected data by final consumers of the product to confirm certification and traceability since early stages of production. In this scenario, a bottle of wine could provide (e.g. via QR code) all the details about the biography of vines. This is one of the most innovative aspects that the wine production cooperative can explore. The proposed architecture can take advantage of blockchain technology to increase trust in the data.

Third, the machine-learning algorithms can take the farmer characteristics in consideration. Future work may include the monitorization of farmers practices (e.g. age, vineyard expertise, digital literacy) to provide recommendations aiming to improve the quality of work (e.g. minimizing the walking distance during field interventions) and resource consumptions (e.g. pesticides and water consumption). The integration of biometric sensors is another opportunity for future research to improve work practices in agriculture.

Conclusion

This research shows how a large vineyard cooperative with near 800 associates prepared their digital transformation integrating the farmers, the vines, the fields, and promoting third party involvement to increase the chances of success. The investment was significant and a minor drawback (e.g. negative effect of sensors in the vine, lack of farmers interest in the tool, possible decrease of data relevance after first use to understand patterns for diseases and alerts) could compromise the entire digital ecosystem of the organization. The results include (1) a real-time ubiquitous system for precision viticulture, (2) suggestions to involve farmers in the platform adoption in daily practice, (3) and a strategy to maximize data value in order to attract researchers, private organizations (e.g. IT providers for system maintenance and evolution), and interface institutions (technology transfer, biotechnology). Intellectual property rights and data protection agreements are necessary in large scale deployments of agriculture 4.0.

This study has limitations to take into consideration. First, although deploying a complete system for the vineyard cooperative, it is essential to continue developing the technology and improving the data collection. A close cooperation with the IT company exploring the solution and the deployment with the associates is important. Second, the research is specific to vineyard production, therefore, other crops may have different requirements and contexts of operation. Third, although we have identified the value of data for research institutions that potentially increase its involvement in the future of the system (e.g. monitor the impact of bio protector microorganisms over time in specific varieties of plants), that part of the research is still under development by the biotechnology institute and requires a few years to produce results. Fourth, there is a risk of the Hawthorn effect suggesting that the observed participants behavior could be "*related only to the special social situation and social treatment they received*" (French 1950). To minimize this effect, we have triangulated different sources of data and contrasted opinions of the experts. Fifth, the literature review focused on the adoption of IT in precision agriculture. There are many studies about the impact/value of IT in other sectors of the economy that could be applied to agriculture 4.0, opening an opportunity for future research in this important area of the economy.

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REFERENCES

Ananda, S., and Paramasivam, K. 2018. "The Impact of Wireless Sensor Network in the Field of Precision Agriculture: A Review," Wireless Personal Communications (98:1), pp. 685–698.

Avison, D. E., Davison, R. M., and Malaurent, J. 2018. "Information Systems Action Research: Debunking Myths and Overcoming Barriers," Information & Management (55:2), pp. 177–187.

Baskerville, R., and Wood-Harper, A. T. 1996. "A Critical Perspective on Action Research as a Method for Information Systems Research," Journal of Information Technology (11:3), pp. 235–246.

Bucci, G., Bentivoglio, D., and Finco, A. 2018. "Precision Agriculture as a Driver for Sustainable Farming Systems : State of Art in Literature and Research," Calitatea (19:S1), pp. 114–121.

Cunha, C. R., Peres, E., Morais, R., Oliveira, A. A., Matos, S. G., Fernandes, M. A., Ferreira, P. J. S. G., and Reis, M. J. C. S. 2010. "The Use of Mobile Devices with Multi-Tag Technologies for an Overall Contextualized Vineyard Management," Computers and Electronics in Agriculture (73:2), pp. 154–164.

Davison, R., Martinsons, M. G., and Ou, C. X. J. 2012. "The Roles of Theory in Canonical Action Research," MIS Quarterly (36:3), pp. 763–786.

French, J. R. P. 1950. "Field Experiments: Changing Group Productivity," in Experiments in Social Process: A Symposium on Social Psychology, J. G. Miller (ed.), McGraw-Hill, pp. 81–96.

Hallin, A., Crevani, L., Ivory, C., and Mörndal, M. 2017. "Digitalisation and Work – Sociomaterial Entanglements in Steel Production," in NFF, Nordisk Företagsekonomisk Förening, Bodø, Norge.

Huuskonen, J., and Oksanen, T. 2018. "Soil Sampling with Drones and Augmented Reality in Precision Agriculture," Computers and Electronics in Agriculture (154:August), pp. 25–35.

Hylving, L. 2017. "Sociomaterial Quasi-Objects: From Interface to Experience," AIS Transactions on Human-Computer Interaction (9:3), pp. 202–219.

Kamran, M., Anjum, M., Rehman, M., Ahmad, H., and Kamran, M. A. 2016. "Classification of Information Systems in E- Agriculture : A Mapping Study," International Journal of Computer Science and Information Security (14:9), pp. 1043–1077.

Lehmann, R. J., Reiche, R., and Schiefer, G. 2012. "Future Internet and the Agri-Food Sector: State-of-the-Art in Literature and Research," Computers and Electronics in Agriculture (89), pp. 158–174.

Leonardi, P. M. 2013. "Theoretical Foundations for the Study of Sociomateriality," Information and Organization (23:2), pp. 59–76.

Leonardi, P. M., and Rodriguez-Lluesma, C. 2013. "Sociomateriality as a Lens for Design: Imbrication and the Constitution of Technology and Organization," Scandinavian Journal of Information Systems (24:2), pp. 79–88.

Matese, A., and Di Gennaro, S. F. 2015. "Technology in Precision Viticulture : A State of the Art Review," International Journal of Wine Research (7), pp. 69–81.

Matese, A., Di Gennaro, S. F., Zaldei, A., Genesio, L., and Vaccari, F. P. 2009. "A Wireless Sensor Network for Precision Viticulture: The NAV System," Computers and Electronics in Agriculture (69), pp. 51–58.

McKay, J., and Marshall, P. 2001. "The Dual Imperatives of Action Research," Information Technology & People (14:1), pp. 45–59.

Morais, R., Fernandes, M. A., Matos, S. G., Serôdio, C., Ferreira, P. J. S. G., and Reis, M. J. C. S. 2008. "A ZigBee Multi-Powered Wireless Acquisition Device for Remote Sensing Applications in Precision Viticulture," Computers and Electronics in Agriculture (62), pp. 94–106.

Nolet, S. 2018. "Seeds of Success : Advancing Digital Agriculture From Point Solutions To Platforms," United States Studies Centre. The University of Sydney (16).

Orlikowski, W. 1992. "The Duality of Technology: Rethinking the Concept of Technology in Organizations," Organization Science (3:3), pp. 398–427.

Orlikowski, W., and Baroudi, J. 1991. "Studying Information Technology in Organizations: Research Approaches and Assumptions," Information Systems Research (2:1), pp. 1–28.

Orlikowski, W., and Scott, S. 2008. "Sociomateriality: Challenging the Separation of Technology, Work and Organization," The Academy of Management Annals (2:1), pp. 433–474.

Popović, T., Latinović, N., Pešić, A., Zečević, Ž., Krstajić, B., and Djukanović, S. 2017. "Architecting an IoT-Enabled Platform for Precision Agriculture and Ecological Monitoring: A Case Study," Computers and Electronics in Agriculture (140), pp. 255–265.

Ray, P. P. 2017. "Internet of Things for Smart Agriculture: Technologies, Practices and Future Direction," Journal of Ambient Intelligence and Smart Environments (9), pp. 395–420.

Rebelo, J., Lourenço-gomes, L., Gonçalves, T., and Caldas, J. 2019. "A Hedonic Price Analysis for the Portuguese Wine Market : Does the Distribution Channel Matter ?," Journal of Applied Economics (22:1), pp. 40–59.

Schwab, K. 2015. "Will the Fourth Industrial Revolution Have a Human Heart?," World Economic Forum. (https://www.weforum.org/agenda/2015/10/will-the-fourth-industrial-revolution-have-a-human-heart-and-soul/, accessed September 3, 2018).

Spachos, P., and Gregori, S. 2019. "Integration of Wireless Sensor Networks and Smart UAVs for Precision Viticulture," IEEE Internet Computing (in press).

Weltzien, C. 2016. "Digital Agriculture – or Why Agriculture 4 . 0 Still Offers Only Modest Returns," LANDTECHNIK (71:2), pp. 66–68.

Wognum, P., Bremmers, H., Trienekens, J., van der Vorst, J., and Bloemhof, J. 2011. "Systems for Sustainability and Transparency of Food Supply Chains – Current Status and Challenges," Advanced Engineering Informatics (25:1), pp. 65–76.

Yoo, Y. 2010. "Computing in Everyday Life: A Call for Research on Experiential Computing," MIS Quarterly (34:2), p. 213.

Yost, M. A., Sudduth, K. A., Walthall, C. L., and Kitchen, N. R. 2019. "Public – Private Collaboration toward Research , Education and Innovation Opportunities in Precision Agriculture," Precision Agriculture (20:1), Springer US, pp. 4–18.