Adoption of digital technologies during the COVID-19 pandemic: Lessons learned from collaborative Academia-Industry R&D case studies

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***Abstract* — The need of lockdown, due to COVID-19, led many manufacturing companies to accelerate the adoption of digital technologies. Manufacturing companies were strongly affected by workforce shortages associated with the spread of COVID-19 and the lockdown, as well by connectivity losses among business partners. Therefore, these companies are reviewing their strategies to increase productivity, mainly embracing digital manufacturing technologies. Here the adoption of digital technologies aims to improve efficiency and flexibility in their processes, also improving connectivity among business partners. This study investigates how collaborative academia-industry R&D cases accelerated the adoption of digital technologies by manufacturing companies, given the current COVID-19 pandemic situation. Based on multiple case studies, this article reports the challenges and the strategies of three ongoing collaborative industry-academia R&D projects developed during the COVID pandemic situation. The results are presented in four different perspectives derived from industry 4.0 readiness maturity models: interpersonal communication, personal competencies and skills, systems integration, and technological strategy. It highlights the importance of manufacturing companies to have a well-designed digitalization strategy, need of continuous training and development of their workforce, and the support of Research & Technology Organizations (RTO) to bring more maturity to the efforts required during a turbulent situation. The results of this paper can provide relevant decision support for manufacturing companies, and its stakeholders, in face of challenges of the actual pandemic and post-pandemic scenario.**

Keywords — digital transformation, adoption, pandemic, COVID-19, manufacturing

I. INTRODUCTION

The use of digital technologies can help companies in their operations and activities, especially in situations where remote operations are mandatory and direct contact is restricted due to the COVID-19 lockdown periods. The lack, or non-adoption, of digital technologies in emerging markets and developing economies can explain why activities in most of these countries remain closed during the outbreak of SARS-CoV-2 and the COVID-19 pandemic lockdown [1].

Pandemic situations lead countries, organizations, and societies in general to discover new approaches to organize their work and economic activities. Due to COVID-19 pandemic, companies are finding new ways for the digitalization of their manufacturing process and the adoption of remote working standards, while evaluating the risk and return on the investment in technologies [2]. Opportunities and risks are present in this turbulent environment, while paradigms for our society and for manufacturing companies regarding business strategy and business models are launched and reinforced, such as sustainability awareness [3] [4] and digital transformation (DT) [5].

Digital technologies perform an important role in business evolution [6] towards new paradigms, such as the established Industry 4.0 approach. This trend, adding to the actual pandemic situation and consequent lockdown, lead to acceleration of the adoption of digital technologies, driven by endogenous and exogenous factors. Before this pandemic situation, many manufacturing companies had launched roadmaps towards DT with different levels of implementation and technological maturity [7]. This means that they already had internal (endogenous) motivation to embrace digitalization, such as Industry 4.0 base technologies. Subsequently due to the lockdown (exogenous), manufacturing companies reacted to the need for social distance by implementing remote working standards and processes' digitalization, while the adoption of new technologies enabled consumers' behavior to become more digitally driven [8].

Several studies exist in the literature concerning the challenges of companies in adopting digital technologies, as well as mentioning the university-industry collaborations in developing innovation projects. However, studies that report the challenges faced by manufacturing companies boosted by the pandemic situation under university-industry collaborations are still scarce.

This paper aims to describe and explain how the lockdown experienced by manufacturing companies during the COVID-19 pandemic situation contributed to accelerate the adoption of digital technologies. Through three cases

presenting academia-industry R&D collaboration, a set of challenges and strategies to overcome such challenges are analysed. In Section II, it is presented the collaboration between academia-industry research and development (R&D), the importance of digitalization for the manufacturing companies and the actual pandemic situation as an element to accelerate the adoption of digital technologies. Then, in Section III, the methodological research framework and three case studies are presented. The case studies report the challenges of ongoing projects during the COVID pandemic situation in three industrial companies and one R&D institution. In Section IV, the results are provided in four different perspectives: interpersonal communication, personal competencies and skills, systems integration, and technological strategy. Lastly, in Section V, conclusions regarding the results obtained in this work are presented. The main conclusions underlines: 1) the importance of organizational elements (culture and workforce) to adopt a DT; 2) the value of communication to a align shop-floor work and tasks, in digital forms; 3) the relevance of training events to provide a learning process in digital technologies; and 4) the purpose of manufacturing companies to co-create a digitalization strategy with a Research & Technology Organizations (RTO).

II. THEORETICAL BACKGROUND

The changes in the processes and results of manufacturing companies are boosted by a complex system of technologies related to each other [9] - presented in the literature as the fourth industrial revolution or Industry 4.0 (i4.0) [10][11][12]. The implementation of the i4.0 paradigm results in a certain level of digital maturity that enables the integration of products and organizational processes using digital technologies, thus improving value for customers and companies [12]. The main technologies that support manufacturing operations systems are big data & analytics (data science and data mining), cloud computing, Internet of Things (IoT), Cyber-Physical Systems (CPS), integrated software systems, additive manufacturing, collaborative robots (cobots), artificial intelligence (AI; deep learning and machine learning), augmented reality (AR) and cyber security [11] [12] [13] [14]. The adoption process of these technologies and their processes is called digitalization [13].

The implementation of digital technologies in manufacturing companies brings several challenges. One of them is the standardization and reference architecture. Therefore, communication, identification, and security standards are required in order to improve the interoperability of different applications and systems [15]. Collaborative partnerships between different companies will only be possible if an architecture framework with a technical description of these standards is developed. Other authors [16][17][18] refer that the actual ICT infrastructures of some companies do not permit horizontal and vertical integration. Another issue is managing complex systems: the higher complexity of systems and products requires appropriate planning and explanatory models for their management [17]. Companies need to adopt a more systemic approach to innovation and technological development, this is, new technologies need to be supported by the company's strategy [16]. It is also necessary a change in management strategies, once it is necessary to adopt open innovation paradigms using systemic platform cooperation - a platform that ensembles actors from industry, academia, government, and civil society [16]. Another challenge is the comprehensive broadband infrastructure for industry: IIoT requires a reliable, comprehensive, secure, and high-quality communication network infrastructure [16][17]. Since a wider variety of large volume transactional data and information will be processed at a high speed, some scalability issues need to be exceeded [18].

However, the potential positive economic, social, and environmental benefits of digitalization [19] can overcome the challenges of implementing these technologies [18]. Reference [16] considers that Industry 4.0 will be the most powerful driver of innovation over the next few decades. Industry 4.0 features are seen as the response to the current challenges – global, highly competitive, and volatile markets, shortened innovation and product life cycles and the increasing complexity of products and services [20].

One of the drivers of digital technologies are universities and Research & Technology Organizations (RTO), responsible for both developing new technologies and supporting companies in their adoption process. Here academia-industry collaboration [21] [22] is key to transfer scientific knowledge to new market solutions, mainly in co-production processes [23]. Even though in some cases the gap between university/RTO and companies hinder the knowledge transfer process, current technological dynamics demand such partnerships to be established through formal (contracts, patents, articles) or informal (personal contacts, student recruitment) paths [24]. Either way, project management techniques are essential to make such a partnership successful.

One of the main barriers in university-industry relations is the different types of knowledge in university/RTO (closer to science, technologically disruptive) and companies (closer to market, technology development driven by current patterns) [25]. Planning, monitoring, controlling and delivering a project may be a challenge when the culture and absorptive capacity of the actors are too different. In addition, the complexity of such technological projects may not only influence project deliverables but also the capacity of the actors to assimilate its developments [26]. Consequently, for academia-industry projects to be successful, formal actions such as defining milestones and the use of management tools, or informal actions such as empathy, trust and communication practices, are important strategies [25].

Given the ongoing DT of companies, and how academica-industry projects may facilitate this process, several scientific articles demonstrate how disruptive scenarios, as this of a pandemic situation, leads companies to adapt themselves and accelerate their digital processes planned (but not already implemented). In the health sector, reference [27] conducted an empirical study to understand the relationship between digitalization and supply chain performance in healthcare manufacturing companies, based on previous research that proposed a role for social capital. Reference [28] evaluate and rank the critical challenges of DTs intervention to control the COVID-19 outbreak. Their results found that Health Information Systems (HIS) was ranked as the first factor among other factors followed by a lack of digital knowledge, digital stratification, economic interventions, lack of reliable data, and cost inefficiency. According to [1] the strategies to survive the 'new normal' imposed by the pandemic situation caused by COVID-19 and intense global competition includes a successful adoption of advanced technologies. In

their article, based on a summary of the articles' synopsis of a Special Issue, they have listed the implementation challenges of state-of-the-art technologies by SMEs in emerging and developing markets. They also address how a lack of adoption and use of advanced technologies has hampered SMEs' business operations during the COVID-19 global pandemic situation.

Reference [29] identified fifteen critical challenges in the implementation of Industry 4.0 technologies in SMEs for ethical and sustainable operations, concluding that SMEs should create knowledge about these technologies and their impacts/benefits for their organizations and for other stakeholders. Management of SMEs should allocate sufficient funds for such initiatives considering its strategic role. More focused on services organizations, reference [30] has a first aim to examine the impact of COVID-19's work implications on employees' performance. According to these authors, COVID-19 outbreak inevitably pushed new ways of working that can become an integral part of the post-pandemic world.

III. Material and Methods

This paper aims to describe and explain how the lockdown experienced by manufacturing companies during the COVID-19 pandemic situation contributed to accelerate the adoption of digital technologies by presenting a set of challenges and the strategies to overcome them. The work developed on this study was based on the case study research methodology, following an inductive research design and using a multiple case study [31] [32]. The complex processes faced in this research comprise thorough, comprehensive empirical descriptions, hence the suitability of the case research design method. Furthermore, through solid literature support and diversified case studies, it was possible to collect insightful scientific data to analyze and construct to extract [31].

With the previous experience and knowledge of the research team, three cases were selected. The cases were collaboration R&D projects between a RTO (academia) and industry, focused on digital transformation. Another criteria to select the projects (cases) concerns the situation where DT was accelerated due to the pandemic situation. These projects were/are running in Portugal: two projects in cork stoppers production and one in graphics and labels production. Data was collected through structured interviews, company reports, on-site observation and workshops with collaborators of all hierarchical levels in all companies.

Case analysis was divided into two stages: (1) within-case analysis, identifying within case patterns and (2) cross-case analysis, searching for cross-case patterns [31]. The within-case analysis, for each company, started with an extensive digital maturity assessment and application of structured interviews in order to evaluate the current status of the companies. A report bringing together and organizing the collected data was written and reviewed by peer-researchers. The data was structured in a standard format to facilitate both the within-case and cross-case analysis. This report resulted in the identification of the main challenges and strategies to overcome them, which led to a specific action roadmap for each company. Moreover, data was synthesized on a table with the purpose to provide an overall view of the results and to simplify the cross-case analysis.

IV. Results

This section presents the results of three academia-industry R&D case studies where the process of DT was in progress during COVID-19 pandemic. We present the main challenges found during the project execution, in a strict collaboration between industry and RTO teams, as well as the applied strategies to overcome them. The challenges as well as the counter measures were identified and derived both from literature and practices as well as field experience from RTO and industry. The strategies proposed are suggestions from the authors considering previous literature, own experience and outcomes from the cases in terms of strategies already conducted.

During the analysis it is possible to identify four major groups of challenges: interpersonal communication, competences and skills, systems integration, and technological strategy. These groups were derived and adapted from two main maturity models for industry 4.0 readiness: acatech [33] and impuls[34].

The first case (C1) relates to a traditional manufacturing company, which bought some other companies. One of the main issues imposed at the time was the development of an integrated information system. The company has a wide range of different heterogeneous and non-integrated information systems, many of them implemented with obsolete technologies. The main objective was to implement one new and full integrated information system, composed of several components. Here machine connectivity, i.e. the extent to which different types of machinery are digitally connected to form a single system, were critical for a proper digital implementation. The fact that many companies' structures have been built up over long periods of time is readily apparent in this area – over the years, these companies have failed to ensure common machine control standards when expanding or successively upgrading their plant. As a result, they now have an assortment of different protocols and data models. Connecting the controllers to newer systems is a job that can only be performed manually and often requires a retrofit. Both these operations call for qualified professionals in control technology and Operation Technology (OT) and Information Technology (IT) integration – two areas where experts are currently in short supply. The actions were accelerated by the current pandemic situation, which has hindered the company's demand for products, while pressuring it towards reducing costs achievable through a digitalization push.

The second case (C2) relates also to a traditional manufacturing company that started as a small medium enterprise (SME) in the 80s and has been growing. The company has now 80 collaborators with 80M annual turnover and, despite the unquestionable growth and success of their business model, there is no clear information system strategy. The company is now struggling on managing their business processes effectively and efficiently due to the fact that their IT system only supports part of the business processes directly related to the financial department, while manufacturing and sales, for example, are based on collaborators' self-developed excel tools. This scenario has deteriorated in light of the COVID-19 pandemic lockdown, since the company relied on constant manual labour to keep up with the activities of their business processes. Thus, there is no visibility nor transparency about the core business processes. A full process analysis and modelling was

conducted, aiming at specifying a complete information system to cover almost all company's business processes in a proper way.

The third case study (C3) focused on the digital maturity assessment of a graphics and labels manufacturing company. Here the project concerns their operational efficiency and overall system's integration, which forced them to look into understanding their current maturity level and to develop a digitalization strategy. Additionally, given that the company is going through a low-demand market due to the current pandemic situation, it was paramount that the possible solutions and actions did not incur heavy financial or labour. Therefore, the goal of the digitalization strategy is to achieve higher efficiency of the manufacturing processes with minimum costs in terms of allocation of resources.

Table 1 presents the main characteristics of the three cases.

A. Results | Interpersonal Communication

Interpersonal communication is a main challenge for all the companies. The communication between different departments is often hard to achieve due to the silos phenomena, where collaborators report directly to a department manager but have no visibility about the whole process. Moreover, communication between business and technology collaborators (both IT and OT) needs to be supported by professionals capable of understanding both domains to achieve a successful digital implementation journey. The pandemic situation is forcing companies to change their interpersonal communication, given that all collaborators are required to have a minimal understanding level of the company's current operations. The reason for this requirement is to allow the scheduling of on-site personnel that are both capable of conducting their own physical tasks as well as conducting their peers' tasks, hence diminishing the need for multiple concurrent workers in accordance with current pandemic regulations. In table 2 the challenges in the interpersonal communication perspective and the strategies to overcome them are presented.

TABLE I. COMPANIES MAIN CHARACTERISTICS

Case / Project ID	***Industrial Sector***	***Classification***	***Project description***
Case 1 (C1)	Cork	MNE	Manufacturing Digitalization
Case 2 (C2)	Cork	SME	Business Process and IT alignment
Case 3 (C3)	Graphics and Labels	SME	Digital Maturity Assessment

TABLE II. CHALLENGES IN THE INTERPERSONAL COMMUNICATION PERSPECTIVE AND THE STRATEGIES TO OVERCOME

Challenge	***Strategy to Overcome***	***Case(s)***
Lack of commitment	Involvement of all stakeholders (from top management to the shop floor worker) in active workshops for brainstorming and opportunities identification	C1 C2
Lack of communication and understanding between IT and OT professionals	Creation of a communication protocol, assuring the effective communication between IT and OT teams, so that different teams (IT and OT) can agree and then work in different threads.	C1 C2 C3
Low level of interdepartmental collaboration. Resistance to Change	Involvement of all stakeholders (from top management to the shop floor worker) in active workshops for the solution design. Thus, anyone will become part of the solution and will support it.	C1 C2 C3
Misalignment between business and technology collaborators	Outsourcing of 'cross-field' professionals, capable of understanding both IT and OT challenges as well as Business needs.	C1 C2 C3

B. Results | Competencies and skills

Competencies and skills for DT are key. It is often observed that collaborators at different levels of organizations have a lack of skills on the technologies already introduced (e.g. information systems: Enterprise Resources Planning (ERP) and manufacturing execution system (MES)). In some situations, these constraints are due to lack of time for training. Yet, given the COVID-19 pandemic, companies have shifted from a focus on infrastructure and operational investments to favor the improvement of their workers' competencies and skills. The goal is to reduce costs and extract higher efficiency from the information systems and operational systems, while also securing in-house talents looking into a digital manufacturing scenario. Table 3 summarizes the challenges and the respective strategies to overcome in this perspective.

TABLE III. CHALLENGES IN THE COMPETENCIES AND SKILLS PERSPECTIVE AND THE STRATEGIES TO OVERCOME

Challenge	***Strategy to Overcome***	***Case(s)***
Lack of digital skills (mainly at shop-floor level	Intensive on the job training on digital technologies to be introduced in the process.	C1 C2 C3
Lack of consolidated knowledge on technologies already implemented at the company due to the lack of time for training	Creation asynchronous training materials for online training in the critical technologies needed for each collaborator work, so that collaborator can learn at his pace. Creation of milestones to ensure the training program execution.	C1 C2

C. Results | Systems integration

Systems integration is one of the main challenges observed in all cases. The flow of information between management and shop-floor is still paper-based. Even in cases where MES systems are implemented, we observe that, as the reliability of digital information is very low, companies maintain the paper records and use it as the 'real' trusted information. This occurs mainly because there are huge technical issues on the integration between IT and OT systems. Machine controllers are highly heterogeneous and most machines need a control system retrofit in order to implement communication enabling technologies. There is no seamless integration between IT and OT systems. Nevertheless, the reduction of demand and, consequently, of sales income on account of the COVID-19 pandemic has pushed companies to look into conducting IT and OT integration improvements in order to diminish operational and technological costs. Table 4 summarizes the challenges and the respective strategies to overcome in this perspective.

D. Results | Technological Strategy

The lack of technology adoption strategy is another challenge identified. Weak sponsorship, lack of holistic digital strategy leads to the creation of several spread technology solutions that are not integrated, which creates

information silos, as well as duplication of information and work. Visibility and transparency of the business process are then compromised. Table 5 summarizes the challenges in this perspective and the respective strategies to overcome.

In terms of starting context, the main similarities identified among the three cases were: (i) all companies had a similar level of information systems implemented; (ii) all companies struggled with having deep knowledge of the functionalities of their ITs and OTs; (iii) all companies had recently gone through a development stage of their manufacturing and information systems focusing on achieving a higher autonomous degree. These results lead us to conclude that companies required a well-designed digitalization strategy, while also considering continuous training and development of their workforce to extract the best results from already established Information and Operation Technologies.

Regarding the effects of the current pandemic situations, it became clear that the companies are having manufacturing scheduling issues due to lack of required personnel on the shop-floor, as well as problems concerning the decreased demand for their products from both new customers and established customers. Moreover, the recent investments on digitalization development from these companies have not yet led to an increase in overall manufacturing efficiency. The main reason behind this discrepancy is the lack of operational knowledge of the new digital tools by the workforce. At this moment, companies are shifting their investments from infrastructure towards culture and workforce in order to extract the best results from their manufacturing capabilities.

TABLE IV. CHALLENGES IN THE SYSTEMS INTEGRATION PERSPECTIVE AND THE STRATEGIES TO OVERCOME

Challenge	*Strategy to Overcome*	*Case(s)*
Weak integration of IT systems. Manual flow of information between the company's departments.	Implementation of middleware flow, assuring the information flow and data consistency between the different IT components	C1 C2 C3
No visibility about the manufacturing process's status. No integration between IT and OT. No real time data available.	Adoption of common machine controller standards, such as OPC for a complete and seamless integration of IT and OT. Machines control system retrofit. Implementation of holistic dashboards, contextualized and adapted for each specific case, so that process owners can manage and decide based on data in near real-time	C1 C2 C3
Very low level of data quality in the current IT systems	Implementations of data cleaning systems. Implementation of data quality assurance mechanism for the new implemented systems.	C1 C2 C3
Across the organization, there is a widespread use of e-mail to exchange documents and important information for the business, compromising document control and causing inefficiencies in the processes	Adoption of document management tools transparently integrated with the business process support systems. For all documents to appear in the context of the process and subject. Different views and ways of searching for documents must be implemented.	C1 C2 C3
It is generally verified that the user interfaces of the applications are not adequate to the tasks that users perform, leading to inefficiencies in the process	Prepare a correct requirements elicitation, within the scope of a business processes analysis, together with the IT department, and with the end users of the applications, in a logic of value co-creation.	C1 C2 C3
There are no comprehensive process monitoring systems, which obliges employees to maintain support Excel files in order to be able to perceive in a discerning way the state of a given process	Implement dashboards suitable for the management of each process or functional area.	C1 C2 C3
ERP systems do not meet the specific needs of the company's operating model, forcing them to develop and adopt non-integrated internal platforms	Adoption of a methodology capable of ensuring ERP developments, in an agile manner, according to the needs of the company, which guarantee compatibility with the base software package.	C1 C2 C3

TABLE V. CHALLENGES IN THE TECHNOLOGICAL STRATEGY PERSPECTIVE AND THE STRATEGIES TO OVERCOME

Challenge	*Strategy to Overcome*	*Case(s)*
Lack of a global digital strategy	Management participation to ensure alignment and organizational commitment. Definition of a broad and coherent, digital transformation roadmap.	C2 C3
Lack of digital transformation process monitoring and evaluation	Appropriate KPIs to manage the calendar and budget	C1 C2 C3
Weak sponsorship	Implementation of Proofs of concept with short delivery times	C1 C2
The company's information system does not follow any strategic plan: it evolves, in a non-integrated manner, according to the operational needs identified by the different stakeholders	Implementation of an IT governance model, aligned with the company's global strategy	C1 C2 C3

V. CONCLUSIONS

Manufacturing companies encounter enormous challenges due to the highly competitive market and the current pandemic context. COVID-19 pandemic situation required new ways to organize works and processes among collaborators, suppliers, clients/consumers, and stakeholders, accelerating the adoption of digital technologies even for companies that have previously started their DT strategy. Based on three academia-industry R&D case studies, four different perspectives related to digital transformation were analyzed (interpersonal communication, personal competencies and skills, systems integration, and

technological strategy). One of the main conclusions achieved in this study is that organizational issues (culture and workforce) are considered structuring challenges for the adoption of digital technologies.

In the analysis carried out from the interpersonal communication perspective, the three cases implemented similar strategies to overcome current challenges. It is noteworthy that, besides the need to create a higher integration among business and technology collaborators, there was a greater need to enhance communication (as a practice of organizational and interdepartmental alignment through digital forms) on the shop-floor. For example, due to sanitary reasons, manufacturing companies had to decrease the number of collaborators working physically (on-site premises) and increase the number of collaborators in teleworking (at home).

To prepare and provide digital technologies, knowledge and learning procedures were available to these collaborators (both *in situ* and outside facilities). All cases presented training programs, adding to the creation of a database for online training in the critical technologies (in two cases), as result of the proposed strategies for the personal competencies and skills perspective. Once again, in these case studies the actual pandemic situation speeded up training events to overcome the scarcity of digital technologies knowledge.

Besides training, the main challenges in these manufacturing companies are related to systems integration due to their low technological level. Integration between IT and OT are still in initial stages and, even after implementing MES systems, the mindset for the full use of these new system tools is still not overcome. Although the COVID-19 pandemic reinforced digital strategies from a systems integration perspective, the progress falls short due to the high investment required, especially in a moment of a global market retraction.

The three cases described in this paper presented insufficient information sharing and absence of workflows, leading to inefficiencies in business processes and divergent data for the decision-making procedure. At the beginning of this pandemic situation, many random initiatives were developed impulsively to accelerate the adoption of digital tools and solutions, instead of a global and holistic DT strategy aligned with the companies' business strategy. However, due to the intervention of the RTO partner in this process, these aspects have been adjusted by combining the companies' global strategy with a comprehensive DT strategy and roadmap.

These outcomes can provide relevant decision support for manufacturing companies, and its stakeholders, in face of challenges of the actual pandemic and post-pandemic scenario. The three cases presented in this article describe a set of strategies to overcome such challenges, emphasizing the importance of digital technologies in this process. This unpredictable and turbulent environment requires both proactive and reactive strategies, addressing organizational and technological transformation and evolution towards the sustainability and competitiveness of manufacturing companies. It is extremely important to emphasize that the collaboration between manufacturing companies and the RTO is vital to assure a proper adoption and knowledge transfer processes.

The results of this study are limited by one RTO and three cases studies: two Portuguese companies in cork stoppers production and one Portuguese company in graphics and labels. For that reason, further studies should consider cases between other universities/RTOs and manufacturing companies from different industrial sectors and countries. Also, because of future relevant new paradigms for our society and manufacturing companies, such as sustainability awareness, future works could relate to the adoption of digital technologies and sustainability.

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