Information Systems Frontiers (2023) 25:995–1016
https://doi.org/10.1007/s10796-020-10047-y

Industry 4.0 Technologies in Flexible Manufacturing for Sustainable Organizational Value: Reflections from a Multiple Case Study of Italian Manufacturers

Emanuele Gabriel Margherita[1] · Alessio Maria Braccini[1]

Published online: 29 July 2020

Abstract

In this study, we analyse the value creation of Industry 4.0 (I40) technologies in flexible manufacturing (FM) under a sustainability perspective. I40 is a popular strategy that Western manufacturing organizations adopt to face competition from low-cost producers. Organizations adopting I40 use advanced digital technologies to make production processes more flexible and increasingly automated. Several pieces of evidence confirm how I40 leads to higher productivity and higher-quality products, improving the economic performance of organizations. However, increasing automation may also lead to the reduction of human labour in the production process, which may contribute to the disappearance of jobs, the reduction of expertise and the loss of know-how in manufacturing organizations. While the literature acknowledges the technical and economic advantages of I40, the sustainability of the value created through these technologies deserves further investigation. To address the gap, we complement the IT value theory with the concept of sustainability, including the three dimensions of economic, environmental and social sustainability. We perform a multiple case study analysis of four Italian manufacturing organizations that have successfully implemented I40 technologies in FM. The cases show that I40 technologies support sustainable organizational value when they are deployed with a worker-centric approach. In this condition, the organization leverages workforce activities to continuously fine-tune the technologies and to exploit the adaptive features of the technologies to continuously improve processes.

Keywords Flexible manufacturing · Industry 4.0 · Sustainability · Triple bottom line · Social sustainability · Multiple case study, technology adoption · IT value · Sustainable value

1 Introduction

Over the last years, the advancement of information technology (IT) has enabled the digital transformation of organizations in many sectors (Matt et al. 2015). The exploitation and integration of IT allows the reshaping of entire business models, thus supporting the creation of novel forms of value for organizations (Mikalef et al. 2020). Consequently, data has become one of the most valuable organizational resources, and scholars and practitioners are particularly interested in studying how digital transformation can support the creation of a sustainable society (Pappas et al. 2018).

In this context, the digital transformation of the manufacturing industry plays a crucial role. Manufacturing is a core industry in a nation's economy (Li 2018) and has already seen a decline in employment levels due to automation (Frey and Osborne 2017; Wright and Schultz 2018). Currently, industrial initiatives that go under the name Industry 4.0 (I40) are furthering the digital transformation of manufacturing organizations to improve the production process, support a sustainable society and create sustainable value generation opportunities (Thoben et al. 2017).

Organizations employ I40 technologies to adopt flexible manufacturing (FM), thus increasing the level of automation, to face competition from low-cost producers (Kagermann et al. 2013). I40 technologies include, for example, the Internet of Things (IoT), robotics, big data analytics and cloud manufacturing (Bednar and Welch 2020; Günther et al. 2017; Kang et al. 2016) and allow the deployment of programmable, interconnected cyber-physical systems that control machinery

✉ Emanuele Gabriel Margherita
emargherita@unitus.it

Alessio Maria Braccini
abraccini@unitus.it

1 Department of Economics Engineering Society and Organization – DEIM, University of Tuscia, Via del Paradiso, 47, Viterbo 01100, Italy

automatically in assembly lines. The way in which organizations use I40 technologies allows addressing problems on the assembly line without human interaction through autonomous machines (Lee et al. 2015).

Several studies in the literature affirm how these technologies improve the economic performance of organizations. I40 technologies in FM enhance the efficiency and flexibility of production processes and deliver economic value in the form of higher productivity, higher-quality products (Fatorachian and Kazemi 2018), optimized logistics performance (Braccini and Margherita 2019; Lee et al. 2015), improved inventory management and shorter time to market (Ben-Daya et al. 2017). Other studies report benefits in the form of a reduced number of work-related accidents, improved workplace safety conditions and improved workforce morale (Braccini and Margherita 2019; Lee et al. 2018, 2017).

While the technical and economic advantages of I40 technologies in FM are clear in the literature, the sustainability of the value created through these technologies deserves further investigation. I40 technologies in FM differ from traditional technologies studied in information systems (IS) research because they target operational activities rather than administrative ones and make them digital (Lasi et al. 2014). Several studies of I40 technologies in FM use a 'technocentric' approach and consider increasing automation as a means to reduce the workforce, thus contributing to the disappearance of jobs (Kang et al. 2016). Even when not replacing people with robots, I40 technologies in FM contribute to the impoverishment of the labour force, as automated cyber-physical systems take on tasks previously performed by human workers (Liao et al. 2017; Nurazwa et al. 2019). I40 technologies in FM may also eventually lead to organizations losing competencies, expertise and know-how (Bonekamp and Sure 2015). The progress in digital transformation changes how organizations work and leads to different interactions among people and in society (Mikalef et al. 2020). Therefore, we believe investigating the value delivered by I40 technologies in FM should go beyond looking at the economic outcome of adopting the technology to examine the sustainable value creation of I40, a perspective that is missing in the literature.

To address the gap, we frame our work within the IT value debate, which mainly focuses on the economic benefits of adopting IT, and look at the triple bottom line (TBL) of sustainability (Elkington 1997). The TBL of sustainability is an analytical framework that considers how organizations address the economic, environmental and social impacts (Jayaprakash and Pillai 2019). According to the TBL perspective, organizations deliver sustainable value and support a sustainable society when they help meet the needs of the current generation without compromising the possibility of future generations to meet their needs. To deliver sustainable value, organizations must seek a balance among economic benefits, environmentally friendly action and human and social capital development (Kiel et al. 2017; Littig and Griessler 2005).

In this paper, we conduct a multiple case study analysis of four Italian manufacturing organizations that have successfully implemented I40 technologies in FM without eliminating jobs. The study answers the research question *How do I40 technologies support sustainable organizational value in FM?* In analysing these cases, we contribute to the literature in two ways. First, we describe how the adoption of I40 technology in FM leads to sustainable organizational value and positive economic, environmental and social sustainability outcomes, thus supporting the development of a sustainable society. Second, we employ the TBL of sustainability in the IT value discourse to analyse the sustainable organizational value of I40 adoption in FM. The structure of the paper is as follows. In Section 2, we introduce the theoretical framing of the paper. In Section 3, we describe the research design, the case selection criteria and the protocol for data analysis and collection. In Section 4, we present the evidence from the multiple case studies. In Section 5, we detail the results. In Section 6, we discuss the implications for both researchers and managers. In Section 7, we offer some conclusions.

2 Theoretical Background

We frame our work within two separate literature streams that we describe in the following subsections. In subsection 2.1, we summarize the debate on IT value and the studies investigating how I40 technologies in FM deliver value. In subsection 2.2, we introduce the concept of sustainability as a means to extend the perspective of IT value studies. In subsections 2.3 and 2.4, we summarize the current state of the art of sustainable value generation of I40 technologies in FM and identify the gaps we aim to address with this research paper.

2.1 Information Technology Value

There is a long-standing debate in the IS literature on the potential economic benefits of investing in IT that has engaged scholars for a long time (Braccini 2011; Melville et al. 2004; Shea et al. 2019). The main question underpinning the IT value debate is whether and under what conditions IT investments deliver economic value to organizations (Devaraj and Kohli 2003; Melville et al. 2004; Scheepers and Scheepers 2008). This question is crucial for both researchers and practitioners to guide them on IT investments and on calculating returns on IT investments (Grover and Kohli 2012; Kohli and Devaraj 2003; Kohli and Grover 2008). Despite some controversial results that support the irrelevance of IT investments for organizational performance (Im et al.

2001; Wagner and Weitzel 2007), several studies confirm that IT investments lead to a variety of organizational benefits.

Early studies pointed out that IT value depends on organizational expenditure on IT. More recent studies have postulated that the way IT is managed within organizations and the environmental context affect the generation of value (Kohli and Devaraj 2003). The research confirms that IT does create value (Grover and Kohli 2012; Kohli and Grover 2008; Melville et al. 2004). The value is not created by individual digital technologies alone but in combination with contextual conditions and in a process that generates value (Melville et al. 2004; Wade and Hulland 2004). The benefits of IT manifest in different forms that are not necessarily immediate (Barua et al. 1995; Kohli and Devaraj 2003). Finally, IT results in profound changes in the way organizations manage their business, and its capability to deliver value is mediated by several factors (Kohli and Grover 2008).

From a theoretical point of view, IT interacts with organizational resources, both human and technical, to improve business process performance and eventually overall organizational performance (Melville et al. 2004). Inside organizations, IT does not deliver value in isolation but rather in a synergic interaction between technological and organizational factors (Kohli and Grover 2008). Contextual factors at the industry level or country level can also influence the actual potential of organizations to obtain value from IT investments (Melville et al. 2004).

To date, studies have concentrated on explaining how and to what extent IT delivers value to increase the efficiency and productivity of organizations (Schryen 2013). IT is generally seen as a driver of various economic benefits, such as cost reduction, business process improvement, improved productivity and improved operational outcomes (Trantopoulos et al. 2017). Much of the literature studies IS aspects such as enterprise resource planning (ERP) and customer relationship management (CRM) that create economic value by improving administrative, managerial and strategical activities, thus facilitating business growth, operational cost reduction, decision making and planning (Shang and Seddon 2000). IT investment at the firm level mitigates the negative effects of downsizing, increases production efficiency (Cespedes-Lorente et al. 2018) and improves cooperation and collaboration among the workforce (Aral et al. 2012). At the macro level (industry or country), IT investment can increase production efficiency and labour productivity (Lee et al. 2011).

Recently, some studies relating to the debate on IT value have shifted the focus to the study of I40 technologies, such as robotics, big data, integrated logistics, and the IoT, as concerns have been raised among practitioners and scholars regarding their value generation potential (Günther et al. 2017; Mikalef et al. 2020; Nicolescu et al. 2018; Pappas et al. 2018). Outside the IS literature, the study of I40 has moved from a technocentric perspective of the technical benefits vis-à-vis assembly line production to discuss the organizational benefits of I40 technologies in FM. The evidence reveals that I40 technologies in FM deliver economic benefits in different ways through increased automation of assembly line production (Kagermann et al. 2013; Lee et al. 2015). I40 technologies in FM promise to deliver higher productivity, higher-quality products and valuable services, enhancing production process efficiency and flexibility (Fatorachian and Kazemi 2018). Furthermore, I40 technologies in FM improve customer satisfaction through the increased personalization capabilities of production processes (Kagermann et al. 2013) and by facilitating the rapid transfer of customer requirements into production processes (Leitao et al. 2016). I40 technologies help generate economic value by improving inventory management effectiveness and supply chain efficiency, with outcomes such as reduced inventory inaccuracy, reduced time to market and just-in-time inventory management (Ben-Daya et al. 2017; Zhang et al. 2018).

2.2 The Concept of Sustainability

To develop a sustainable society, organizations must move from value generation to sustainable value generation by prioritizing sustainability goals (Hart and Milstein 2003). According to the Brundtland Report, the concept of *sustainability* is described as a form of economic development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987 p. 43). The concept of sustainability encompasses the association of environmental protection with societal development that must be addressed by organizations together with their economic development objectives (Elkington 1997). Therefore, the concept of TBL sustainability (Elkington 1997; Jayaprakash and Pillai 2019) that concerns the economic, environmental and social impacts of activities is particularly relevant.

The economic aspect relates to the organizational idea to generate economic value in order to guarantee the possibility of delivering products and services to the market with a mark-up between revenues and costs, either through increased added value in the production or through cost reduction during the production process (Kiel et al. 2017). The environmental dimension refers to the organizational idea to create value in order to alleviate pressure on the environment through rationalizing the use of natural resources, efficient energy consumption, renewal energy consumption and reducing emissions and pollution (Braccini and Margherita 2019; Hertel and Wiesent 2013). The social dimension refers to the organizational idea to create value in order to conduct fair business practices to benefit the workforce, the community and society in general. This dimension broadens the perspective of the organization to cover all stakeholders. It requires the organization to manage long-term survival and simultaneously deal with social issues related to community involvement, employee relations, fair wages, quality of life, social integration in communities, solidarity, equity and justice and equal opportunities in education (Kiel et al. 2017).

The economic, environmental and social dimensions of sustainability are interdependent. To achieve sustainable value creation, organizations need to embrace all three dimensions in their business models (Jayaprakash and Pillai 2019). However, the three dimensions are frequently in conflict, as actions in pursuit of environmental or social sustainability do not always turn into improved economic sustainability.

2.3 Sustainable Organizational Value of Industry 4.0 in Flexible Manufacturing

I40 technologies in FM deliver organizational value in terms of better management of resources along the assembly line, better management of operational activities, improved coordination on the assembly line and reorganization of labour within the production system (Fatorachian and Kazemi 2018; Kagermann et al. 2013; Kamble et al. 2018; Thoben et al. 2017). Literature investigating I40 technologies in FM is still emerging, but there is sufficient evidence on the potential economic benefits of I40 technologies measured in terms of higher-quality products, higher productivity, shorter lead time, improved customer satisfaction and timely and accurate management of the movement and allocation of resources along the assembly line.

The implementation of I40 technologies also generates benefits in terms of the environmental dimension of sustainability through improved control over resource usage thanks to more accurate and granular information on energy and resource usage (Liang et al. 2018; Schulze et al. 2018). I40 technologies also help decrease the number of product defects and damaged products and reduce both waste in general and natural resource waste in production processes (Gabriel and Pessel 2016; Herrmann et al. 2014). Furthermore, I40 technologies help in extending the lifespan of products, thus helping improve consumer consumption of sustainable products (Bressanelli et al. 2018). However, the environmental dimension is known to be in conflict with the economic dimension, as environmentally sustainable products and processes are costly for companies, and customers tend not to be willing to pay more for cleaner products and services (Liu et al. 2009; Liu and Bai 2014).

The literature shows contradictory results regarding the value of I40 technologies in terms of the social dimension. The positive outcomes relate to improved safety and healthier work conditions (Fatorachian and Kazemi 2018; Kagermann et al. 2013) and manifest in the form of fewer accidents, healthier work environments and improved worker morale (Braccini and Margherita 2019; Lee et al. 2018). However, the literature also describes a negative consequence of automation from the social sustainability perspective that conflicts with economic sustainability. This is that the adoption of I40 technologies in FM decreases the role of human resources through de-skilling and reducing the number of both low- and high-skilled workers as they are replaced by machines (Bonekamp and Sure 2015; Kang et al. 2016; Liao et al. 2017; Nurazwa et al. 2019).

2.4 Gaps of Sustainable Organizational Value of Industry 4.0 in Flexible Manufacturing

Table 1 summarizes the state of the art of the sustainable value of I40 technologies in FM. To date, most studies have considered one dimension of the TBL and have not addressed the three dimensions holistically. There is a large consensus on the potential economic benefits of adopting I40 technologies in FM, and the literature describes several technical and operational advantages. However, most of the studies adopt a 'technocentric' approach (Kang et al. 2016). The technology is the main driver of the improved production effectiveness, and the workforce is just seen as an organizational cost. This is because with I40 the way human resources add value in the organization changes (Bonekamp and Sure 2015), and there is a potential risk of the loss of worker competencies and a reduction in employment levels (Liu and Zhong 2017; Nurazwa et al. 2019).

The risk of technology replacing people is inherent with any technological development and has occurred with previous innovations in production, such as with the adoption of computerized information systems and mass automation. The case of I40 technologies in manufacturing is different because, unlike computerized information systems used in administrative functions in organizations, I40 technologies are used in operational units. The number of workers employed in manufacturing is significantly higher than the number employed in administrative functions. In addition, if mass automation has reduced the number of workers it has been compensated for by the expansion of markets thanks to increased consumerism. A similar change is less likely today with saturated markets.

The literature highlights that increasing automation positively impacts workforce activities, delivering positive outcomes relating to the individual dimensions of sustainability (Gabriel and Pessel 2016). With I40 technologies in FM, operational and decision-making tasks are passed to machinery, while human workers deal with machinery malfunctions and unexpected issues (Gabriel and Pessel 2016; Kagermann et al. 2013). I40 technologies in FM create healthier and safer environments around workers. The workforce benefits in the form of better working conditions, fewer severe accidents and improved morale (Gregori et al. 2018; Kembro et al. 2017; Lee et al. 2018). At the same time, I40 technologies in

Table 1 State of the art of sustainable value of I40 technologies in FM

	Attributes	References	Short Description
Economic Dimension	Improved production process	(Fatorachian and Kazemi 2018; Kagermann et al. 2013; Thoben et al. 2017).	FM promises to improve production process, delivering higher productivity, higher quality products and valuable services.
	Improved customer satisfaction	(Braccini and Margherita 2019; Fatorachian and Kazemi 2018; Kagermann et al. 2013)	FM applications improve customer satisfaction through the increased personalization capabilities of production processes.
	Increased supply chain efficiency	(Ben-Daya et al. 2017; Lee et al. 2018; Zhang et al. 2018)	FM applications improve the efficiency of supply chain management, thus reducing inventory inaccuracy.
Environmental Dimension	Reduction of natural resource and energy usage	(Bressanelli et al. 2018; Kagermann et al. 2013; Schulze et al. 2018)	FM applications reduce natural resource usage and result in energy savings via more precise data granularity vis-à-vis technology.
	Reduction of CO_2 emissions	(Gabriel and Pessel 2016; Herrmann et al. 2014; Liang et al. 2018)	FM applications better manage the logistics between the production process and warehouse, thus reducing transport and CO_2 emissions and decreasing fuel usage.
Social Dimension	Reduction in number of work accidents	(Braccini and Margherita 2019; Gregori et al. 2018; Kagermann et al. 2013; Yuan, Qin, and Zhao 2017)	FM technologies automate unhealthy and dangerous production phases.
	Improved workforce morale	(Fatorachian and Kazemi 2018; Kagermann et al. 2013; Lee et al. 2018)	Workforce enjoys a better work environment oriented more towards workers' needs.
	Increasing safety at work	(Braccini and Margherita 2019; Kagermann et al. 2013; Kembro et al. 2017)	The deployment of I40 technologies increases safety across the production process.
	Workforce substitution	(Kang et al. 2016; Liao et al. 2017).	By automating, I40 technologies reduce the size of the workforce employed in the production process.
	Reduction of workforce core activity	(Bonekamp and Sure 2015; Nurazwa et al. 2019).	I40 technologies accomplish core tasks that workers were previously in charge of.

FM offer the potential to extend the tenure of senior workers in the workplace by reducing physical strain (Stock and Seliger 2016).

We find a gap in the current research on the sustainable value creation of I40 technologies in FM. One issue is the lack of a comprehensive assessment of the value delivered by I40 technologies in light of the TBL of sustainability. Several studies have focused on individual dimensions without considering rebound effects on the other dimensions. Few have considered the multi-dimensional aspect of sustainable value creation holistically. Another issue relates to the different nature of the three dimensions of the TBL, which can conflict with each other.

The conflict between the economic and environmental dimensions is described in the literature, but we also find a conflict between the economic and social dimensions of the sustainable value of I40 technologies in FM that results in a trade-off. I40 technologies lead to increased automation and better work environments. The consequences are a potentially de-skilled staff and reduced staff or a longer work life and thus less generational change in the workforce. Under this perspective, we find the outcomes of adopting I40 technologies in FM contradictory. On one side, I40 technologies in FM contribute to putting products of higher quality and higher value on the market. On the other side, they contribute to a social environment with potentially poorer customers (as staff is reduced and new generations do not replace older ones). The contradiction emerges from the fact that the adoption of I40 technologies helps improve processes and organizational performance but at the same time contributes to reducing the spending capacity of the workers replaced by machines, leading to a society with a decreased ability to buy higher-value products.

3 Research Design

In this paper, we performed a multiple case study analysis because it favours the collection of rich data in multiple contexts (Yin 2018). This methodology allows for cross-case comparisons to clarify whether the findings are idiosyncratic to a single case or apply to several cases (Yin 2018). Multiple case study analysis allows establishing patterns of relationships between constructs within and across cases with their underlying logical arguments by recursive cycling among the case data. The method consists of selecting multiple cases, triangulating data during data collection and analysing the data both within cases and across cases (Eisenhardt 1989; Yin 2018).

3.1 Case Selection

In this paper, we analyse four cases selected according to four criteria:

1. The case units are manufacturing organizations.
2. All case units share similar contextual (country = Italy) and structural dimensions (medium-sized manufacturing organizations).
3. The case units operate in different industries in manufacturing.
4. The case units adopted I40 technologies to implement FM.

Concerning the fourth criterion, we opted to include organizations adopting various I40 technologies for FM, which allowed us to study the different ways the implementation of I40 technologies in FM create value while addressing sustainability issues. Table 2 describes the I40 technologies adopted by the cases in this study. All the cases transitioned from traditional production to FM through the adoption of I40 technologies.

We consider the following exemplary cases (Yin 2018) because they allow us to explore how the management of I40 technologies in FM currently and potentially address sustainability issues. The cases are described below.

- Case A: This is a manufacturer of sanitary ceramics that implemented mechanical arms and automated forklifts in a fully automated and integrated process in which workers perform supervisory roles and fine-tune IoT-controlled machinery. The company also has a traditional labour-intensive process in place.
- Case B: This is a kitchen furniture manufacturer that automated part of the transformation process in which workers supervise IoT-controlled machinery and that deployed IS on the assembly line to support workers in the assembly task.
- Case C: This is a leather manufacturer that integrated digital technologies to improve the traceability of materials and operations on the assembly line in a tracking system that assists workers and provides visibility in terms of the time and costs needed to complete lots and to respect performance targets.
- Case D: This is a manufacturer industry that produces orthopedic prosthesis that adopted autonomous mechanical arms in the manufacturing process in which workers have a supervisory role and perform manual tasks to finalize the product. The company also integrated a tracking system for materials and operations using barcodes.

3.2 Data Collection

In this multiple case study, we triangulated different data sources (Denzin 2006). We had the opportunity to visit each organization in 2019. Each visit lasted approximately three hours, during which we conducted semi-structured interviews with key informants among the workers and the management following the track indicated in Table 3. The management interviewees were the chief executive officer (CEO), the chief production officer (CPO), the chief information officer (CIO) or the chief human resource officer (CHRO) and chief quality officer (CQO). We also chose to interview the entire steering committee that drove the innovation in each organization. Among the workers, we decided to interview a representative employed before the adoption of I40 technologies who remained with the company after the adoption. All interviews were conducted face-to-face, recorded and transcribed. All the respondents are males aged 40–60, except the CHRP and CPO of Cases C and D, who are females aged 30–50.

Guided by the management, we observed the production lines, the operation of smart machines and control systems and the activities performed by workers on the line. Table 4 presents the data sources in detail.

We transcribed the interviews and compiled field notes after the observations, which we added to the data we analysed. We made use of secondary data in the form of official balance statements of the companies that provided information on the companies' financial performance, the official web sites of the companies and web articles to reduce subjectivity regarding the adopted I40 technologies in FM. We acquired the latter from the official web page of the companies and included them in the data corpus, as they provided further details regarding how the companies create sustainable value. Finally, we collected all the data sources in a data corpus and integrated it into a single research database for each case, which we coded following the guidelines for the validity and reliability of qualitative inquiry (Corbin and Strauss 2015).

3.3 Data Analysis

We conducted data analysis and cross-case analysis using computer-assisted qualitative data analysis software (CAQDAS) as a supporting tool. We joined the transcriptions of the primary and secondary sources of data in a single research database. In total, we coded about 20,000 words of interview transcriptions and field notes and 38,000 words of secondary data. We made use of both first, and second-level codes. We first analysed data from each case, identifying how managing the adoption of I40 technologies in FM created sustainable value. To maintain qualitative rigour, we followed the principles of qualitative enquiry (Corbin and Strauss 2015). We then conducted cross-case analyses, comparing the findings across cases. We explored similar concepts and relationships across cases, comparing the categories identified from each case. Only one of the two authors coded the

Table 2 Industry 4.0 technologies in flexible manufacturing

Industry 4.0 Technology	Description
Internet of Things (IoT)	A dynamic WiFi network infrastructure comprising mechanical technologies equipped with sensors (RFID, barcodes, actuators). These sensors allow real-time capturing, processing and communicating of data by and to other technologies and humans.
Integrated logistic	A set of devices used for automating warehouses through fully automated conveyors and for producing integrated and timely data about products in stock.
Robotics	Autonomous or collaborative devices capable of performing specific tasks. Robots can be fully automated and self-moving machines that can manage material picking and handling inside a warehouse or programmable mechanical arms that can perform desired manipulation tasks, such as modelling, welding, gripping or cutting.
Tracking systems	Set of integrated systems that use mobile devices, barcode scanners, QR code scanners and image recognition to trace work and material flow on the assembly line. The system can be either automatic or manually operated by workers using manual barcode scanners.
Data analytics	Set of integrated systems that provide visual and real-time feedback on workers on the assembly line. The feedback can be related to costs, time benchmarks or operational instructions on the assembly tasks to perform on components, products or by-products.

materials in CAQDAS. Both authors regularly discussed the results of the coding together. The single coder coded the materials in several iterations; this was followed by discussions with the other author. The coding procedure stopped when both authors agreed on the results of the coding.

We arrived at the findings after three iteration rounds and adopting a two-fold saturation criterion: (i) all the data sources could be coded with the set coding structure and (ii) the research team agreed on the results of the coding. When there were conflicts in the accounts of the participants, we organized follow-up phone calls for clarifications. Table 5 illustrates the coding data structure used in our analysis. We provide a sample of the coded materials from all cases in Table 11 in the appendix.

4 Case Description

In this section, we describe the four cases. For each case, we describe the production process, the changes introduced with I40 technologies in FM and the consequences in terms of sustainable value outcomes of FM implementation.

Table 3 Interview track

Interviewees	Questions
Management (CEO, CIO and CPO)	Type and extensions of I40 technologies in FM
	Motivations and conditions triggering I40 technologies in FM
	The sequence of actions performed during the implementation of I40 technologies in FM
	Consequences for the production processes after I40 technologies in FM
	Economic sustainable value of I40 technologies in FM
	Social sustainable value of I40 technologies in FM
	Environmental sustainable value of I40 technologies in FM
	Organizational dimensions: employee number, years of activity, turnover level
Workers	Type and nature of the work performed in the organization
	Experience (if any) with the traditional production process
	Benefits for the worker after adoption of I40 technologies in FM
	Personal awareness of the benefits of the adoption of I40 technologies in FM
	Changes in working conditions before and after the adoption of I40 technologies in FM

Table 4 Details of data sources

Cases	Data Sources		
	Observations	Interviewees	Secondary data
Case A	Traditional assembly line, I40 assembly line, R&D unit	CEO, CIO two supervisor workers of assembly line workers one R&D responsible worker	official balance statements, official website, web interviews and articles
Case B	Traditional assembly line, I40 assembly line, automated warehouse, traditional warehouse	CPO, CQO two supervisor workers of the production unit one responsible worker of automated warehouse	official balance statements, official website, web articles
Case C	Traditional assembly line, I40 assembly line, IT units, product development units, warehouse	CEO, CIO, CHRO one supervisor worker of the assembly line unit	official balance statements, official website, web articles
Case D	Traditional assembly line, I40 assembly line, warehouse, administration unit, IT unit	CIO, CPO one supervisor of production unit workers	official balance statements, official website, web articles

4.1 Case A

Case A is a manufacturer of sanitary ceramics. Before the adoption of I40 technologies, the company's production process was labour-intensive and dangerous for the health of workers. During several production steps, workers were subject to inhaling soft powder (chalk). They also worked in a high-temperature environment (the working temperature of the oven is about 1200°) and carried heavy loads. Workers manually operated machines and moved products and materials down the assembly line. Any mismanagement in terms of handling the materials could decrease the quality of the product or increase the defect rate. Information about the production process was collected manually and was limited to the amount of outputs.

The company then adopted I40 technologies in FM and improved the production process with self-driving forklifts, automated robotized arms and fully automatic conveyors. All this machinery is integrated through IoT, resulting in a fully digital audit trail of operations keeping track of materials, workers and machines. In this integrated assembly line, the intervention of humans is limited to a few machine tasks that could not be fully automated. Generally, the workforce supervises the automatic operations and continuously improves the process by fine-tuning the machines to reduce the defect rate and improve output quality. To that end, the company introduced CAD and CAD designers to design products and set up an internal R&D department. The R&D department continuously experiments with materials and production steps to facilitate further product and process improvements.

The transformation of the assembly line took five years. The management planned the innovation and discussed the plan with all workers, presenting the investment as necessary to guarantee the long-term survival of the company in a market dominated by low-cost producers in countries with low labour costs. It was soon evident that the innovation resulted in a significant change in workforce operations and competencies. The company offered workers the opportunity to leave if they were not willing to learn new skills, and all those who accepted were enrolled in vocational training courses over the course of the five-year transformation. At the end of the transformation of the production process, the company kept in place the traditional process for small batch customer orders with limited quantities.

The transformation resulted in a number of different outcomes: output increased by 30%; lead time decreased, even with a broader variety of products; the defect rate plummeted from the original 30% down to 9%; and the use of resources (energy, water, heat and raw materials) was optimized. The I40 machinery monitored the entire production process; the tracking of goods improved, and order fulfilment inaccuracy decreased. The data produced are now continuously analysed, resulting in comprehensive reports on the status of the machinery and predictions regarding future production trends.

The workers' duties were also enriched. The company kept the old and the new assembly lines. New employees work next to skilled workers on the old assembly line to learn the technicalities of the work. When they are deemed ready, they move to the I40 assembly line and act as supervisors who optimize the machines. The knowledge dimension of the work increased. On the assembly line, workers program the machines to be more efficient and avoid defects and autonomously solve issues when the machines stop. They also provide feedback on any malfunctions of the I40 technologies to improve the production process. The company also required new R&D capability and therefore hired new employees with the

Table 5 Coding data structure

1st Level Coding	2nd Level Coding	Theoretical concepts
Reduction of raw material usage Reduction of paper usage	Reduction of energy usage and natural resources	Environmental sustainability
Energy saving		
Fewer faulty products Less damage to products during the production process	Reduction of waste and faulty products	
Sustainable raw materials Wood from sustainable farms	More sustainable products	
Flexible daily production quantity Increased control over the production process	The more efficient production process	Economic sustainability
Reduction of lead time		
Workers aware of their daily performance		
Less loss of order information Increased information flow among units	Better circulation of information	
More accurate information flow between outbound logistics and suppliers		
Workers as machine supervisors Workers with novel quality assurance duties	More responsibility for workers	Social sustainability
Increased task autonomy for workers		
Less powder in the warehouse Less sawdust close to the machinery	Better work conditions	
Reduced temperature on the assembly line		
I40 technologies in charge of unhealthy activities		
Reduced physical stress for workers		
Workers with more knowledge of raw materials Workers with more competencies for each production step	Workers with appropriate competencies	
Workers with appropriate competencies to manage I40 technologies		
Competencies increased by vocational courses		
Novel IT unit Novel production unit	New business unit	
Novel R&D unit		
Novel administration unit		

necessary skills. In the study period, the earnings before interest, taxes, depreciation and amortization (EBITDA) remained stable and, after a decline at the beginning of the transformation in 2015, the workforce remained almost constant (see Table 6).

4.2 Case B

Case B is a manufacturer of custom kitchen furnishings which assembles standardized furniture parts to deliver kitchens configured on the bases of customers' needs. Before the adoption of I40 technologies, workers cut components from wood panelling with semi-manual cutting machines. They manually picked up the components, transported them along the assembly line, assembled them and delivered them to the warehouse. Information on the process was in the form of paper-based bills of components that workers used to assemble the furniture. The process was inefficient due to a high defect rate caused by the mishandling of materials and offered limited product customization possibilities. The work was physically exhausting, and part of the production environment was potentially unhealthy due to the presence of sawdust.

After adopting I40 technologies in FM, the cutting phase became fully automated through the use of mechanical arms and digitally programmable sewing machines. This machinery optimized the cutting phase, maximized the number of components obtainable from a standard wooden panel and reduced waste and dust. The outbound phase of the production process was also automated, and the warehouse was equipped

Table 6 Balance sheet report for Case A

	2018	2017	2016	2015	2014	2013	2012
Sales	45.851.907 €	47.480.153 €	48.585.072 €	43.278.017 €	39.293.103 €	36.334.943 €	35.494.315 €
EBITDA	12.984.069 €	13.269.796 €	14.933.236 €	11.293.393 €	8.147.484 €	6.123.442 €	36.334.943 €
Net Profit	6.090.089 €	5.376.088 €	6.292.911 €	4.114.905 €	1.591.308 €	1.248.504 €	2.032.215 €
Workers	223	233	224	237	237	267	284

with IoT sensors. The movement of furniture parts in the warehouse is now autonomous. In the warehouse, the finished products are sorted and grouped according to customer order and the delivery destination to optimize space (5,000 components are now stored in the same space previously used to store 1,000 components). The assembly phase is still manual. Computer screens are used to show workers the assembly instructions, and semi-automatic conveyors present the components to the workers in the right sequence to minimize the number of movements and simplify their work. Excluding those employed in the assembly phase, workers supervise the machinery, checking the production phases, product quality and specifications for the rest of the production process. The innovation took three years, and workers attended vocational training to learn how to work with the new machines.

The innovation had several outcomes, including the optimization of resource usage and the reduction of waste. Exhausting and dangerous tasks were transferred to autonomous machinery, thus reducing work accidents and resulting in a safer environment free of sawdust and powder. The workforce activities are now more complex, and workers have greater responsibility, as they also act as machine supervisors. Workers are also in the change of providing feedback to improve the machinery operation, as they have direct experience of how the machinery works. Experienced workers have a further duty to teach younger workers to manage the technology through on-the-job training. After the implementation of I40 technologies, the company had to employ more workers. Table 7 illustrates that after the adoption of I40 technologies in FM in 2017, the EBITDA increased along with the sales and profits. The number of workers also steadily increased because the improved quality of the products increased demand.

4.3 Case C

Case C is a textile manufacturing company where the production was entirely by hand before the adoption of I40 technologies. The process had four phases—manual cutting, dyeing, assembly and packaging. The list of components circulated along the assembly line on paper. The workers used this to manually mark production progress. The process lacked accurate information on time and quantity produced in each phase and in total. The company improved the process by adopting a traceability system with advanced analytics to accurately measure the time for each production step. The company developed the system in-house and established an IT department to manage and maintain it. The granularity of data is at the microphase level and traces each worker, phase and product. Furthermore, the IT and HR departments developed a competence pattern and illustrations to facilitate the production for each microphase.

The management informed the workers about the innovation project and provided vocational training to learn how to work with the new technologies. In the new process, workers use a tablet that contains the interface of the traceability system and the target for production time and costs. The advanced analytics system produces performance statistics and displays them in real time on TV screens on the assembly line. The screens display the targeted performance level with a green smiley face if on target or a red one if not on target. Using reports produced by the data analytics system, the managers can identify workers who regularly perform below standards and discuss with them counter-measures to improve their performance, including the possibility to attend vocational courses, to train to improve skills or to discuss the pace of the work. Workers who perform well receive extra compensation. Thus, the workers are motivated to complete the production steps in less time.

The adoption of FM results in more efficient production, better coordination among units, reduced waste and a reduced defect rate. The time spent on production steps is also reduced. The tablet helps workers perform better by providing detailed, visual instructions on the movements they need to perform to avoid mistakes. The workers can manage the tasks they perform by helping each other, in particular to speed up underperforming lines. They are supported in this by the screens showing the trends of daily production in real time and comparing the trends with the target set for each day.

The workforce also becomes more proficient in the competencies required for crafting leather through vocational training. In fact, apprentices acquire a specialisation over the entire production process and experienced workers acquire competencies in different production steps and reinforced knowledge about the production steps they are in charge of. Table 8 shows the situation after the transition to FM in 2017.

Table 7 Balance sheet report for Case B

	2018	2017	2016	2015	2014	2013	2012
Sales	106.860.231 €	106.852.829 €	95.226.687 €	84.353.953 €	78.028.435 €	73.069.252 €	74.128.291 €
EBITDA	8.514.515 €	8.434.987 €	6.225.339 €	4.714.540 €	3.170.375 €	3.079.452 €	2.924.582 €
Net Profit	4.245.683 €	4.509.915 €	2.439.406 €	1.394.957 €	454.426 €	7.799 €	79.445 €
Workers	203	187	179	170	163	160	159

EBITDA and sales increased, while the number of employees remained almost stable.

4.4 Case D

Case D is a manufacturer of orthopaedic prostheses where production was executed manually by workers. The prostheses must be custom designed, tested on the clients and refined by workers to improve the ergonomics and improve the clients' range of motion to the maximum extent. Before the adoption of I40 technologies, workers employed production sheets to manage the production steps. These sheets also provided information to orthopaedists in case of production delays. The production took place in an unhealthy work environment with chalk powder in the air. In addition, the information concerning time and performance was inaccurate. The process was done manually by workers who used pen and paper to record the time it took to perform the various tasks. These records were often incomplete, as workers often forgot to mark time or mismarked it. This lack of information caused problems in administrative processes as well. Patients needed to visit the company several times to get their prostheses and invoices.

After the adoption of I40, the process improved. The use of robotized arms and a tracking system to keep track of the time spent on each step of the production process increased efficiency. The system uses barcode scanners and is integrated with the digital billing system. Workers attended vocational training to learn how to work with the new I40 technologies. The management also established a new digital administration unit. The administrative and production information is now integrated, and the company is able to track the clinical history and bills of the patients.

The new production process is semi-automated; the robotized arms develop the initial shape and surface of the prostheses in a separate room, and the workers refine the prostheses manually. The workers supervise the mechanical arms, which increased production flexibility, reduced the use of chalk and thus improved working conditions.

Along the production process, workers employ a tablet to mark the start and finish time for each production step using barcode scanners. The system gathers data from the production process and provides real-time information to orthopaedists and descriptive statistics to the management. The system data are integrated into the digital billing system, which delivers a bill when the prostheses are finished.

The information flow and traceability of the process are now improved. The improved information accuracy helps orthopaedists with subsequent prosthesis modification because the system stores the clinical history of the patients. Through the tracking system, FM has resulted in increased efficiency because the workers do not waste time with manually reporting information. In addition, the possibility of making mistakes has been reduced. Workers can now just focus on improving product quality. The system also improved the process of ensuring alignment between technical information about the protheses and administrative billing information for customers. Table 9 illustrates that following the FM adoption in 2017, EBITDA and net profit increased by 65% and 97%, respectively, whereas the number of workers increased by two units.

5 Analysis and Findings

Table 10 summarizes the outcomes of the adoption of I40 technologies in FM for the case companies. Several outcomes

Table 8 Balance sheet report for Case C

	2018	2017	2016	2015	2014	2013	2012
Sales	9.729.992 €	10.898.420 €	8.063.020 €	7.635.606 €	8.509.532 €	10.039.060 €	9.460.818 €
EBITDA	515.170 €	620.941 €	283.911 €	338.536 €	301.233 €	667.140 €	607.607 €
Net Profit	181.053 €	251.571 €	57.168 €	59.879 €	62.447 €	207.621 €	200.271 €
Workers	90	86	92	93	93	94	96

Table 9 Balance sheet report for Case D

	2018	2017	2016	2015	2014	2013	2012
Sales	16.967.339 €	17.229.166 €	16.822.189 €	16.731.097 €	15.556.783 €	14.634.219 €	13.702.293 €
EBITDA	1.502.983 €	907.456 €	1.164.817 €	1.011.499 €	962.919 €	1.463.312 €	847.169 €
Net Profit	810.412 €	410.249 €	285.092 €	319.416 €	284.311 €	21.606 €	144.815 €
Workers	99	97	91	79	78	75	61

are consistent across all the cases, while others are particular to just some. Concerning the economic dimension of the TBL of sustainability, the results show in all cases that the adoption of I40 technologies in FM created value through a more efficient production process and better circulation of information. The production process efficiency is manifested by different performance indexes—level of output, reduced defect rate, improved product quality and reduced lead time. In Case A and Case B, the improved circulation of information was instrumental in the performance improvement, as information produced by I40 machinery can be continuously used to scrutinize process performance and spot improvement opportunities. In Case C and Case D, better information circulation is evident in the integration of technical and administrative data, which contributes to improving accuracy in handling customers' orders. Furthermore, better information circulation also helps workers, as they are able to view their performance and the performance of the whole line in real time and compare them to benchmarks or targets.

Concerning the environmental dimension, the analysis revealed how the production processes became more efficient after the adoption of I40 technologies in FM, with reduced residual waste, a decrease in the number of defective products and rationalized use of natural resources and energy. In Cases A, B and D, the reduction of waste and number of defective products (which cannot be reprocessed) is a consequence of introducing automated machinery that can perform difficult tasks more easily and that can handle the materials more accurately and optimize the use of raw materials. In Case C, the reduction of waste is the consequence of the use of digital technologies that guide workers on the operations they have to perform to reduce mistakes.

Concerning the social dimension, a main outcome of the adoption of I40 technologies in FM for all case companies is better work conditions. In Cases A, B and D, the automation through robots reduces the number of labour-intensive tasks for workers and reduces the likelihood of workplace accidents or becoming ill (e.g. as a result of inhaling fine particles of powder). In Case C, the tracking system helps workers keep the pace and visualise their performance in real time and reduces the stress of potential disputes with management regarding the level of performance. The workers also gain improved competencies and new skills for working with I40 technologies in FM in all cases. Companies can then defend the workers' positions, as many employees who possessed only artisan skills in the traditional production process remained in the company as operators. In all cases, we found new positions to fully exploit the adoption of I40 technologies in FM. However, these positions appear to replace or transform existing ones due to the profound difference in competencies between traditional manufacturing and FM. The new positions are knowledge-intensive jobs that exploit the information produced by I40 digital assembly lines to run either R&D activities or continuous improvement activities.

The social dimension differs the most across the cases, as we found some outcomes only in some specific cases. The analysis of the cases revealed different forms of empowerment of the workforce that depend on the characteristics of the production process and are therefore not consistent across the cases. The forms of empowerment are related to either the shift from operational to supervision roles, better knowledge of the overall production process or the possibility of making decisions on the content of the tasks needing to be performed, suggesting improvements and solving problems on the assembly line. The conflicts in the literature are between the economic and environmental dimensions and between the economic and social dimensions.

We also found increased worker control over the tasks they perform, the possibility to self-organize to help each other in teams or on the assembly line and the possibility to suggest how to change the pace or other aspects of the production process. However, the evidence is not consistent across the cases, as we did not observe these outcomes in all cases.

6 Discussion

According to the literature, I40 technologies in FM contribute to the development of a sustainable society by creating sustainable value in manufacturing organizations when they address all the dimensions of the TBL. Any technology in an organization should be implemented to achieve meaningful outcomes and generate business value (Mikalef et al. 2020). The literature shows that the creation of sustainable value through I40 technologies is challenging for organizations, as

Table 10 Sustainable value of I40 technologies in FM by sustainability dimension

Case(s)	Sustainability Dimension	Outcomes of I40 Technologies in FM
All	Economic	A more efficient production process
All	Economic	Better circulation of information
All	Environmental	Reduction of energy usage and natural resources
All	Environmental	Reduction of waste and faulty products
All	Social	New organizational positions/units
All	Social	Workers with improved competencies
All	Social	Better work conditions
All	Social	More responsibility for workers
A, B, D	Social	Workers act as supervisors of I40 technologies in FM
A, B	Social	Empowerment: workers provide feedback for improving the FM production process
C	Social	Workers with improved competencies/knowledge of the entire production process
C	Social	Continuous improvement of worker competencies through tailor-made vocational training
C, D	Economic	Use of tablets facilitates workers' task through pictures and production patterns
C	Economic	Empowerment: increased task autonomy for workers

the three dimensions of the TBL are in conflict (Braccini and Margherita 2019; Kiel et al. 2017).

In particular, the economic dimension and the social dimension conflict, as I40 technologies can contribute to improving the performance of a firm but also cause the social dimension to deteriorate due to the de-skilling of workers or a reduction in the level of employment (Bonekamp and Sure 2015; Nurazwa et al. 2019). Manufacturing organizations have already experienced automation and a consequent disruption of work for blue-collar workers (Frey and Osborne 2017). The adoption of I40 technologies continues this erosion, thus hampering the development of a sustainable society. The analysis of our cases revealed that I40 technologies can be adopted in FM to support all the dimensions of sustainability

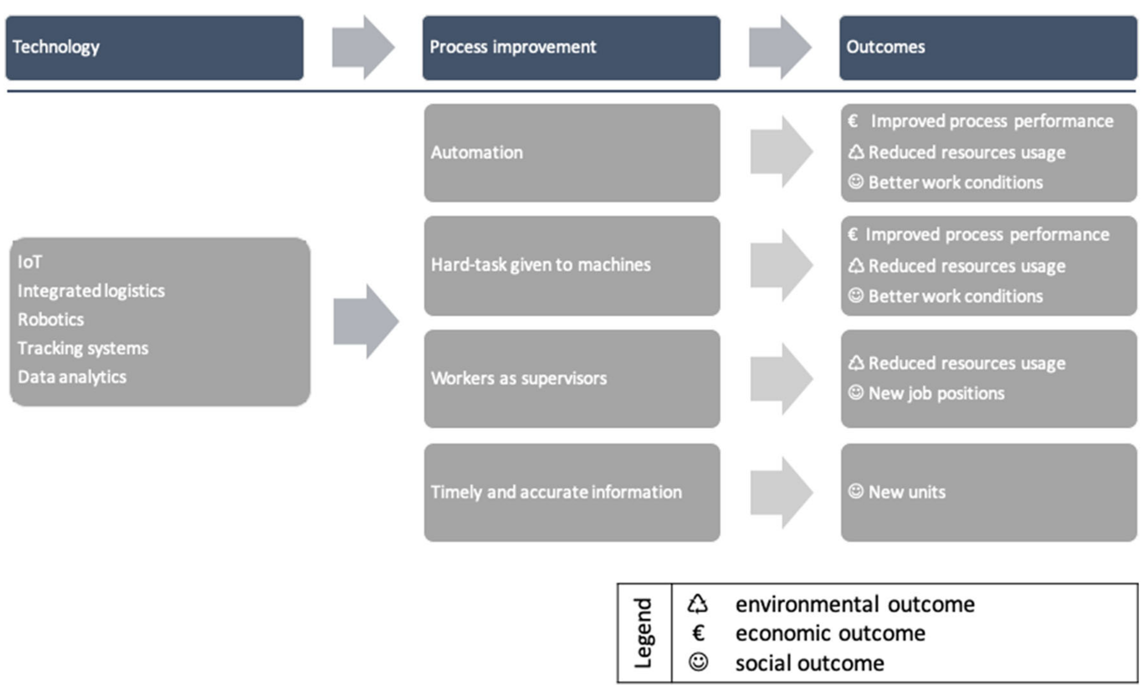

Fig. 1 Sustainable organizational value generation by I40 technologies

and thus can deliver sustainable organizational value and contribute to building a sustainable society.

In line with the IT value theory, I40 technologies in FM deliver economic value through various process improvements that eventually improve organizational performance measured by economic performance indicators. The process improvements introduced by I40 technologies are in the form of increased automation, using automated machinery for dangerous tasks, human supervision of machinery and timely and accurate information. These improvements lead to sustainable organizational outcomes for all three dimensions of the TBL—improved process performance (economic), reduced resource usage (environmental) and better work conditions, new job positions and new units (social).

Improved process performance translates into improved economic performance, as companies can deliver high-quality, defect-free, customized products to the market. The reduced resource usage promotes more sustainable products and services thanks to the reduced need for energy and the reduction of waste. While the better working conditions have a motivational effect in terms of workers' morale (Braccini and Margherita 2019; Lee et al. 2018; Lee et al. 2017), the need to have skilled supervisors and the availability of timely and accurate information offer workers new opportunities to take on new roles and responsibilities, with several new knowledge-intensive positions appearing in organizations and new job roles on the assembly line. Such opportunities contribute to social sustainability, as in this way organizations implementing I40 technologies in FM can defend employment levels and promote a sustainable society. On one side, the number of workers required declines due to automation. On the other side, organizations can offer workers with the right skills and knowledge jobs operating I40 machinery or positions related to planning, controlling and researching that the shift to FM stimulates. Figure 1 visually summarizes how I40 technologies in FM support sustainable organizational value creation.

Under this perspective, data plays a crucial role in supporting the organizational sustainability of manufacturing companies and thus in the development of a sustainable society. I40 technologies on the assembly line allow companies to collect data on processes, which previously was unfeasible. The growing amount of organizational data lays the foundation for novel roles, as companies require a highly skilled workforce capable of analysing and managing that data. Thus, companies compensate for the disappearance of jobs due to automation with novel positions related to data management.

However, we believe such results are only possible when I40 technologies are deployed with a worker-centric approach to enhance the capabilities of the workforce and thus improve the production process. Indeed, the management considered the features of automation delivered by I40 technologies in FM as a resource to improve the economic sustainability of the companies, avoiding the mere adoption of technologies that could be easily imitated by competitors. Therefore, these organizations leveraged workers' activities, including supervision, experimentation and feedback to improve the production process. The application of this worker-centric approach pushes organizations to automate all the tasks that are dangerous or in which workers might make more mistakes (resulting into an increased defect rate).

The worker-centric approach has two consequences—increased knowledge intensity and continuous adaptations of I40 technologies. These consequences can further contribute to sustainable organizational value. The need for workers proficient in managing digital I40 technologies and the availability of data produced by the technologies increase the relevance of the knowledge dimension of manufacturing as workers move from manual crafting activities to activities related to the utilisation of technology and related problem-solving. Within a knowledge-intensive organization, workers enjoy less alienating working conditions and a higher degree of job satisfaction.

The composition of the workforce has changed both in the FM production process and within companies where several knowledge-intensive positions have appeared. The commitment to improve the production process has been pursued by both workers who perform activities with a high level of knowledge and act as primary drivers of continuous fine-tuning of the FM production process and by units related to I40 technologies. The analysis showed that in the case companies the adoption of I40 technologies in FM is accompanied to the insurgence of adaptive units (such as R&D units), production control units, or administrative units all exploiting the information produced by the I40 machinery.

Another aspect of the social sustainability of I40 technologies in FM is the increase in employment levels due to companies' success in the market (like in our Case B). This requires companies to employ more workers to increase the number of work shifts to increase output levels. However, it is relevant to point out that such an increase requires a profound transformation of the workforce, as people need to learn new skills through vocational training. The number of employees is defended or increased, but they are not the same employees that were in the company before. Only in one case did the organization succeed in maintaining both the old and the new production processes. In this way, they could keep workers with old competencies. However, further research is needed to prove generalizability.

From a process perspective, I40 technologies allow to easily incorporate these improvements to optimize automation of the production process. For instance, whether technology experts change the algorithm of the FM production process, I40 technologies afford the production process to receive and apply these new movements. Likewise, in case of the development of a new mixture or utensils for the production process, I40 technologies afford to harmonize movements and afford to handle them accordingly. To describe this feature, we employ the term *adaptive* to refer to technology possibility to easily implement these process improvements to optimize automation. The cases showed that this feature is applied in different ways in the production processes to improve the adaptability of the process—in essence, the change of materials and material flows in the process (Cases A and B), the change of the sequence of operations on the same machine (Case B) and the change of workers' activities based on monitoring information (Case C). Hence, within the FM context continuous adaptation does not necessarily lead to the disappearance of jobs, as happened with mass-scale automation (Bonekamp and Sure 2015; Kang et al. 2016; Nurazwa et al. 2019).

Moreover, the cases show the importance of management in choosing and undertaking a worker-centric approach in adopting I40 technologies. We argue that management plays a crucial role in the development of a sustainable society. Indeed, management could exploit automation to increase economic performance but at the same time reduce the level of employment. In contrast, the cases show management's commitment to deploy I40 technologies to improve productivity, reduce natural resource usage and defend jobs. The cases also show the importance of management actions before the adoption of I40 technologies when they develop change management projects to address production issues and foresee the organizational opportunities associated with I40 technologies and the possibility of improving work conditions.

We posited that the adoption of I40 technologies in FM generates sustainable value when deployed with a worker-centric approach and with continuous adaptation of I40 machinery. This approach encourages the transition to knowledge-intensive companies in which the core activities of workers shift from crafting activities to activities related to the utilization of technology and associated problem solving. This transition requires a number of knowledge-intensive positions. The workforce benefits from less alienating working conditions and a higher degree of job satisfaction. I40 technologies in FM should be designed to be continuously adapted for receiving and implementing improvements, thus enabling workforce activities to improve the FM production process.

6.1 Implications for Researchers and Future Avenues of Research

Our study has certain implications for researchers. Future studies of I40 technologies in FM should adopt a broader research design and consider a more extensive and complex socio-technical system. Our work contradicts the statement that I40 technologies lead to reduced employment levels (Bonekamp and Sure 2015; Kang et al. 2016). The transformation induced by I40 technologies in FM encompasses the whole organization, and new positions appear in other units and not just on the assembly line. Because IT value manifests in different ways (Kohli and Grover 2008), the focus to study impacts of I40 technologies should be larger than the task and the tool used to perform it. The larger focus is necessary because the outcomes can appear in other tasks and tools activated by the outcomes produced by the technology (improved performance, timely and accurate information).

Another implication relates to investigating the raise of novel knowledge-intensive positions consequent to the implementation of I40 technologies in FM. Future researchers should investigate how to manage knowledge within FM organizations and how organizations deal with the transition of knowledge when there is significant turnover. This includes dimensions related to the use of the data produced by the I40 technological infrastructure to generate knowledge. We believe this is a fruitful avenue of future research, particularly because the next technology that will impact FM is artificial intelligence. Artificial intelligence may change the interplay between the workforce and I40 technologies, for example, by automating more substantial decision-making activities. Therefore, artificial intelligence can potentially harm the sustainable social outcomes created by I40 technologies we identified, with even more tasks moving from workers to machines. Thus, artificial intelligence has the potential to hamper the development of a sustainable society, as it can disrupt the novel knowledge-intensive roles created to manage I40 technologies and the associated data.

Our study also invites IS research, which often focuses on the impact of administrative systems and data, to study IS in production departments and to investigate how data generated by I40 technologies on the assembly line can be integrated with the rest of the data organizations possess (Lasi et al. 2014). Future studies should investigate how and to what extent the I40 data retrieved from assembly lines are managed to create sustainable value for each dimension of sustainability. Our study is a starting point for further investigations, as it describes several technologies—notably the tablet containing the tracking system—to increase control of the workforce to deliver value. How does this data deliver additional value to organizations without raising concerns about privacy, surveillance and control of workers? In our study, we found forms of worker empowerment. However, they are not consistent across all the cases. Instead, in every case, workers are in a production environment where managers have a complete audit trail of their actions and performance.

Analogously, our study extends the perspective of IT value, employing the TBL as an analytical framework to assess sustainability. With the TBL, researchers studying IT value can extend their enquiry into sustainable organizational value. Given the contextual societal situation, sustainable organizational value is an objective that organizations need to achieve. Hence, we see an avenue for future research to investigate how IT can contribute to delivering sustainable organizational value.

In this study, we investigated four manufacturing companies, all located in Italy. While we acknowledge this as a limitation of the paper, we believe it does not reduce the significance of the study, as Italy is a relevant context for investigating I40 in FM because the country is the second-largest manufacturer in Europe[2]. The results of our study are mostly generalizable in organizations operating in the European context that share similar characteristics – firm size, industry type, and level of governmental support to the adoption of these technologies – to the Italian context. Nevertheless, we encourage researchers to investigate the sustainability of the adoption of I40 technologies in FM in other contexts and countries, including developing countries, Asian countries and North and South American countries.

6.2 Implications for Practitioners

Practitioners can use the results of our work as a guideline for FM organizations aiming to implement I40 technologies and to reduce resistance to change by workers scared of losing their jobs. Our study shows that I40 technologies in FM deliver sustainable organizational value, and it describes the potential outcomes that organizations can expect from the adoption of these technologies. Our results can also help practitioners address potential resistance to change by workers. Based on the case results, the role of the workers in a worker-centric deployment of I40 technologies is central for sustainable organizational value. Vocational training plays a crucial role and should be provided for each worker employed in the FM production process. The continuous improvement of the FM production process is also possible through the continuous action of workers with the competencies to manage FM technologies and provide feedback on the way they work. Thus, the transition to FM production processes does not automatically imply a reduction in the employment level.

The study is also useful for policymakers aiming to develop incentives to improve worker conditions and boost innovation in the manufacturing industry. To date, most industrial initiatives provided financial support to organisations to buy I40 technologies through reduction of tax and favourable credit terms. Knowing how I40 technologies contribute to sustainable organizational value in FM, policymakers may develop more organic incentives that do not aim at stimulating the acquisition of the technologies but instead promote sustainable digital transformation of manufacturing.

Finally, our study helps experts in the design of I40 technologies to shift from a 'technocentric' approach to a worker-centric approach where the workforce has a prominent role in the production process. Our study showed how the interplay between technology and people leads to sustainability value, increased production efficiency and 'humanizing' work by addressing the three dimensions of sustainability.

7 Conclusion and Limitations

In this study, we investigated the value generation of I40 technologies in FM from a sustainability perspective. By combining the IT value theory with the concept of the TBL of sustainability, we investigated how I40 technologies contribute to delivering sustainable organizational value based on the pieces of evidence of a multiple case study. I40 technologies in FM generate sustainable value when deployed with a worker-centric approach and with a continuous adaptation of how the technologies work. I40 technologies lead to improved process efficiency and more timely and accurate process information. The improved performance of the process is manifest also through reduced energy usage and waste. I40 technologies move work from workers to machines, but they promote the raise of new job positions and units in the organization that either exploit the data produced by the technologies on the assembly line, or they further improve production capabilities through R&D or increasing amount of output.

The study has some limitations. First, it is based only on four cases, all of which are located in Italy. However, to reduce this limitation we selected cases from different industries. Moreover, the cases selected are representative of the second-largest manufacturing country in Europe. Second, we intended to investigate all three dimensions of sustainability. However, our primary data mostly focuses on social and economic sustainability and less on environmental sustainability. To offset this, we enriched our analysis by triangulating different sources, which allowed us to obtain a clear and subjective picture of the remaining dimension.

Appendix

In this section, we present with Table 11 the most significant excerpts for the dimensions of the analysis and with Table 12 the legend of roles.

[1] Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E): https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_na_ind_r2&lang=en, retrieved: 09/01/2020.

Table 11 Sample of coded materials

Topic		Coded material
Economic sustainability	The more efficient production process	This FM application is the first in the ceramic industry. We risked a lot, but now our production increased by 30%. We increased control over the processes, and we also produce high-quality products (Case A, CEO).
		I am making tests to find the best conditions for baking ceramic to improve quality. We will program the robots on the assembly line according to the parameters I will find (Case A, R&D Worker).
		FM application cuts move and store parts efficiently by an automated cutting machine, a mechanical arm and a pioneer automated warehouse. We now produce in-house all the goods according to the orders we received (Case B, CPO).
		The innovative production system, which the company is a pioneer in the adoption, is positively impacting economic performance, reducing time spent on each product production (Case B, web article).
		We required a technology that allows us to improve our crafting skills rather than to replace workers as this technology would be a replicable asset. We increased our production quality (Case C, CEO).
		We self-manage the production with Tv monitors because now we know how much we produce per day. Also, the competence patterns in the tablet help to improve our works (Case C, Worker).
		Case C has become one of the most innovative companies in the leather industry. Case C increased the turnover by 10% through an innovative production system (Case C, Web Article).
		The workforce role is changing as now they use new technologies that require more knowledge and specializations for their tasks. The manufacture of products increased (Case D, Web recorded interview).
		The mechanical arm is in charge of the first part of the prosthesis production, improved the productivity and reduce time spent on production. The worker now is a supervisor of the technology (Case D, CTO).
	Better circulation of information	Now we integrate information flow through these technologies along the production process. With this technology, we reduced damaged products from 30% to 9%, maintaining the production constant without mechanical issues (Case A, CPO).
		This technology integrates the production process with the warehouse. We always now which available products we have in our warehouse (Case B, CPO).
		We integrate outbound logistics with the supplier system; the supplier can send a suitable truck to transport the products (Case B, CPO).
		The IS improved data circulation among the organizations; we can now track the products advancements for each product (Case C, CPO).
		The tablet IS interconnects the organization providing statistics of the production process. The application measures better our processes, particularly production advancement (Case D, CPO).
Environmental sustainability	Reduction of energy usage and natural resources	The company has an ISO 14001 certification. They reduced usage of water, heat and energy through an efficient production process, and installed solar panels (Case A, web article).

Table 11 (continued)

Topic		Coded material
		We recover heat from the oven in order to dry chalk molds for the next phase saving energy. Also, we recover and reuse all the water employed in the production. We filtered this water; thus, we can use it for the next production (Case A, CPO).
		CPS retrieve the orders and optimize the wood paneling saving wood, which came from certified sustainable farms. CPS also integrate available parts. The production process now runs without interruptions avoiding energy waste (Case B, CPO).
		We automated outbound logistic phase, and we group orders to reduce transports and movements within the organization—also, the automated warehouse help for this objective (Case B, CPO).
		We reduced usage of paper along the production process thanks to the IS in Tablet and also administration unit now is paper-less because workers are completely digitalizing it (Case D, CTO).
		The key to sustainability is to control with information systems the process; thus, we can reduce paper and prepare alert in case workers make mistakes, thus reducing production waste (Case D, CPO).
	More sustainable products	In the R&D laboratory, they are continuously testing new and sustainable mixture to produce ceramics (Case A, CPO).
		Case B is environmentally friendly. They have an ISO 14001 certification and employs sustainable wood with FSC certification (Case B, web article).
	Reduction of waste and faulty products	We automate the handling of products by autonomous forklifts with a resulting reduction of damaged products that cannot be reprocessed and therefore waste (Case A, CEO).
		Our client sends us top-quality leather. We reduced leather wastes from productions through competences of workers since it is not possible to automate this process (Case C, CPO).
		The automated cutting machine passes the products to the mechanical arm, which drop then in a cart, reducing the number of damaged products (Case B, worker).
Social sustainability	Workers with proficient competences	The company improves workforce conditions through I40. The worker has been requalified now they are technology experts. Now technologies move product in automation and workers control the system through a computer. Case A also provides several vocational courses for workers (Case A, web recorded interview).
		R&D workers have increased their knowledge of raw materials for ceramics thanks to vocational training and their experiments here (Case A, CPO).
		I attended vocational courses for more informatics competences. Now I place parts at the entrance of an automated warehouse, which store parts and I control the system in front of the computer before I moved and stored parts into the warehouse by forklifts (Case B, worker 2).
		Workers positively accepted the technologies as they realize how much produce for organisations. They know better all the steps of productions (Case C, CPO).
		We provide vocational courses if workers spend too much time on tasks or commit a production mistake. Vocational courses

Table 11 (continued)

Topic		Coded material
		production powders (Case D, CPO).
	More responsibility for workers	I am supervising these machines producing ceramics. The work I do now is less manual and more mental. I can activate and deactivate the machine, and I try to figure out if there is a better way to let it work (Case A, worker).
		I am teaching my colleague to use this technology. In six months, he will be independent (Case B, worker 1).
		Before the work was 90% manually, we moved too many parts. Now I supervise the machine that does these hard tasks with two other workers while before I was alone. Now I have more responsibility as I check the quality of parts (Case B, worker 1).
		The production process remained the same, but now we can improve manufacturing because we can work in each phase of productions. We have more responsibilities now (Case C, Worker).
		Some of us were moved from the production line to manage the mechanical arm. We received vocational courses to use the software of a mechanical arm (Case D, Worker).
	Establishment of a new unit related to FM technologies	We settled the R&D laboratory. They search a sustainable and enduring mixture to use for our production. We hired workers to maintain the laboratory, and we provide vocational courses to them each month (Case A, CPO).
		We settled a new laboratory for materials research. We are the first in the ceramics industry (Case A, CEO).
		Did you see the new production unit? It is in a different plant since it required more space. We adopted new cutting

Table 11 (continued)

Topic		Coded material
		are excellent. Our region government also certifies them (Case C, CHRO).
		The company won a price for the academy which intensified competences of workers through vocational courses and provided guidance for apprentices (Case C, Web Article).
		The worker supervision the machine has artisan competences in crafting the prosthesis and acquired further competences in the usage of technology through training courses (Case D, CPO).
	Better work condition	Workers thanks us for these technologies. Now, the worker is close to the mechanical arm. In case of mistakes of the mechanical arm, he can detect them and halt production. The temperature is now more adequate in the production process (Case A, CPO).
		Before we worked with a scorching temperature, now, these technologies improved our conditions mitigating the temperature (Case A, worker).
		Look, the production technologies are inside this cage which block powders of productions and sawdust is sucked from that hole. The workplace now is cleaner (Case B, CPO).
		Workforce activities are enjoying significant improvements in the day-routine activities through the innovative production system (Case B, web article).
		Workers now always know the advancement of production; they do not spend time searching paper along with the production phase (Case C, CPO).
		We automate the first part of the prosthetist production, with a mechanical arm in a separate room. Now the workplace has fewer

Table 11 (continued)

Topic	Coded material
	machines and an automated warehouse. (Case B, CIO).
	Management settles an IT unit to develop our IS on a tablet. The IT units also manage the gather data providing statistics regarding our production process and the worker performance (Case C, CEO).
	This is the IT unit; all the IS retrieve all the data in this database. We can analyze data in real-time. We can analyze both the daily production and the daily and monthly performance of each worker (Case C, CPO).
	The Digital Administration unit became important. We hired two workers to move in digital all the admirative bills. We also integrate this system with the production process IS (Case D, CTO).

Table 12 Legend of roles

Acronym	Description
CEO	Chief executive officer
CIO	Chief information officer
CPO	Chief production officer
CHRO	Chief human resources officer
CQO	Chief quality officer

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Emanuele Gabriel Margherita is a PhD Candidate at the Department of Economics Engineering Society and Business (Dipartimento di Economia Ingegneria Società e Impresa - DEIm), University of Tuscia, Viterbo (Italy). During his PhD, he was a visiting student at Information Systems Department of Agder University (Norway) and the LENTIC research centre at Liege University (Belgium). His research focuses on how Industry 4.0 technologies create sustainable value for organizations and society. His work has appeared in *Sustainability Journal*. His research has been presented at STPIS, WOA and ItAIS conferences.

Alessio Maria Braccini is an Associate Professor of Business Organization and Information Systems at the Department of Economics Engineering Society and Business (Dipartimento di Economia Ingegneria Società e Impresa - DEIm), University of Tuscia, Viterbo (Italy). He holds a PhD in Management of Information Systems from the LUISS Guido Carli University, Rome (Italy). His research interests concern the study of the impact of ICT at the individual, team, and organizational levels. His research has appeared in journals such as the *Information Systems Journal (ISJ), Information & Organization (I&O), International Journal of Accounting Information Systems (IJAIS), the Government Information Quarterly (GIQ)* and the *Communications of AIS (CAIS)*. His work has also been presented at ICIS, ECIS, BIS, MCIS, ItAIS, and WOA conferences.