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Industry 4.0 and supply chain process reengineering: a co-production study of materials management in construction

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ABSTRACT

Purpose – This paper contributes to the literature about supply chain process management by discussing how Industry 4.0 technologies can support process reengineering in the context of the construction industry.

Design/methodology/approach – The paper discusses the impact of Industry 4.0 technologies through an exploratory case study focused on the materials management process, using a co-production of research approach where the main findings are obtained through the involvement of internal and external process actors.

Findings – The results show that the introduction of Industry 4.0 technologies could radically improve process performance, better supporting the execution of activities, increasing the effectiveness of communication between actors, and favouring data collection and sharing. These technologies, characterized by the level of risk connected to their implementation, need to be introduced in combination with new organizational mechanisms, which may be beneficial for several supply chain actors.

Originality/value – Through the adoption of a research co-production methodology – which is not common in the literature – this paper contributes to the ongoing discussion about how Industry 4.0 technologies contribute to process-centric supply chains, by discussing the benefits of these tools from the perspective of process actors.

Keywords: Supply Chain Management; Business Process Management; Industry 4.0

1. Introduction and research motivations

A supply chain is the set of a company's entire operations directly and indirectly interlinked and interacting to transform inputs into outputs that are delivered to the end customer, and is composed of a set of arcs and nodes, interconnected by information flows, material flows, and cash flows (Power, 2005). Supply chain management (SCM) is the attempt to bring order into this complex system, and so there is a need for knowledge about the network and the business processes in order to manage such a complex network (Lambert and Cooper, 2000), which are different in nature and traditionally categorised as plan, source, make, deliver and return activities (Prajogo and Olhager, 2016).

Many scholars have considered how SCM could be more efficient and effective through the greater employment of digital technologies (Liu et al., 2016b), allowing the sharing of information beyond organizational boundaries (Wu et al., 2014). In fact, supply chain processes and organizational performance rely strongly on both information and knowledge sharing, information management and data sharing play an essential role in improving supply chain processes, and technology has revolutionized how supply chain actors achieve better alignment (Prajogo and Olhager, 2012; Reaidy et al., 2015; Wang et al., 2016). Nowadays, thanks to the so-called fourth industrial revolution, Industry 4.0 (I4.0), and the diffusion of the associated newly pervasive digital tools (I 4.0 technologies), technology is dramatically changing the way supply chain processes are managed and the level of cooperation among supply chain partners (Fawcett et al., 2011). Indeed, according to the Industry 4.0 vision, digitalizing firm processes smooths the integration of firm departments and supply chain members (Ardito et al., 2019).

Such technologies, however, have also been recognized as difficult to implement, as they involve deep transformations in the way supply chain processes are executed (Fan et al., 2015; Liu et al., 2016b). More and more companies have therefore decided to employ a structured business process re-engineering (BPR) approach to introducing these innovations. In fact, BPR is a structured approach to business process redesign which overcomes the limitations of actual process design by promoting radical changes which leverage new IT capabilities and technologies (Satyal et al., 2019). In many industries, the use of BPR has become crucial to achieving higher competitiveness through improved processes that can add value (Roglinger et al., 2012), as process management is the foundation of a supply chain's better performance (Lusch, 2011). Among the different levers for improvement proposed by BPR, technology plays a central role, often paired with a redesign of organizational aspects (Weske, 2012; Davenport, 1993).

Some industries are directly exposed to the challenges connected to the redesign of supply chain process supported by I4.0 technologies (Rebuge and Ferreira, 2012). Of these, construction is an interesting unit of analysis because projects are characterized by complex organizations (Jia et al., 2011), interaction between multiple actors (internal and external; Ruan et al. 2012), and a need to exchange several materials flows, and a significant amount of information (Hwang and Ng, 2013).

I4.0 technologies are the new trend for companies today, and their implications have been studied in various industries and with focus on different processes (e.g., Ardito et al., 2019; Müller et al., 2019; Savastano et al., 2019). For instance, the deployment of big data analytics in business processes has been found to shape ambidextrous business process management in terms of exploitation and exploration (Dezi et al., 2018), while the capability of an organization to manage big data analytics-capable business processes increases the agility of ambidextrous organizations. (Rialti et al., 2018). Despite the relevance of such implications, however, empirical studies of the implications for business processes using I4.0 technologies are limited (Dezi et al., 2018).

Among other things, there has been debate about the diffusion of I4.0 technologies to support supply chain processes with a focus on the construction industry (e.g., Dallasega et al., 2018), but the potential and scope of these tools are still unclear. In particular, little is known about the implications of the high human component which characterizes process execution in this context, and can prevent I4.0 technologies being fully introduced and exploited without the agreement and full collaboration of process actors.

On this basis, this paper contributes to both the BPR and SCM literature by analysing the opportunities provided by I4.0 technologies to improve supply chain processes in the construction industry, and the implications for the organization. In this way, it helps in understanding how to reach an alignment between digitalization, technology implementation and supply chain management, as suggested by Büyüközkan, and Göçer (2018).

Starting from the supply chain needs of complex construction projects, we explore how more extensive use of I4.0 technologies could better support supply chain processes in this context, in order to answer the following research question:

RQ1. How can the application of I4.0 technologies support supply chain processes in construction?

We use an exploratory case study of process reengineering (Fawcett et al., 2012) focused on materials management. By recognizing the need for a bottom-up perspective when introducing disruptive technologies in processes (Wei et al., 2011), the paper considers the potentialities provided by I4.0 applications in supporting material management activities using an employee-driven approach, in the spirit of a co-production of research between the process actors (internal and external) and the research team. This, as well as being an original perspective, also provides an opportunity to understand the organizational impact of technology introduction, and to thus answer the following question:

RQ2. How do organizational mechanisms need to be adapted to favour the better adoption of I4.0 technologies?

The paper is organized as follows. The following section presents an overview of the main theoretical aspects that represent the foundation of this work. In Section 3, we provide details about the case under analysis and the collaborative research design approach used. In Section 4, the primary evidence from case analysis is reported. Finally, Sections 5 and 6 summarize, respectively, the main findings of the study and the contribution these results can provide to the academic and practitioner fields.

2. Literature background

2.1 The role of I4.0 technologies in improving supply chain management processes

Among the different levers with which to improve business processes, technological innovation plays an important role– especially when the focus is on supply chain manufacturing, logistics, procurement, warehousing, planning and analytics activities (Rosemann and vom Brocke, 2015).

Supply chain "*process digitalization*" is the strong adoption of digital tools for the strategic and operational management of information and material flows along the chain in all supply chain processes (i.e., Kache and Seuring, 2017; Büyüközkan and Göçer, 2018). Meier (2016) recognizes eight digital technology trends in SCM, connected to the I4.0 revolution: 1) mobility; 2) big data analytics; 3) cloud computing; 4) social media; 5) predictive analytics; 6) the internet of things (IoT); 7) 3D printing; and 8) scanning robotics; these innovations need to be integrated as much as possible at process level, in order to create more effective and efficient supply chains.

Researchers claim that I4.0 technologies are expected to improve SCM processes performance. In fact, process digitalization and the I4.0 revolution aim to improve flexibility, productivity, and customer orientation by interconnecting the process in the supply chain (Müller et al., 2019). This can lead to an improvement in supply chain risk mitigation and prevention (Ivanov et al., 2019). Finally, in the context of process digitalization, I4.0 has provided a further impulse to technology implementation in the broader manufacturing and distribution environment (Klitou et al., 2017), thus also impacting other companies and processes.

2.2 How to improve supply chain processes leveraging I4.0 technologies

In this section, we discuss, first, the approach to supply chain process improvement, business process reengineering (BPR), and then, in the light of the characteristics of BPR, the need to investigate the potential impact of I4.0 technologies on the organizations and the human resources in a company to ensure smooth and successful I4.0 technologies implementation.

2.2.1 The business process reengineering approach

As discussed in the previous section, the impact of I4.0 technologies on SCM processes has the potential to make significant improvements in a process's performance through a radical rethink of the way in which processes are managed. This idea falls within the scope of "business process reengineering" (BPR), a managerial philosophy promoting a radical rethink and redesign of the business processes (Hammer, 1990), through the introduction of improvements in order to increase overall performance. The BPR approach is presented in the literature as being significantly interdependent on information technology, as the Massachusetts Institute of Technology first proposed it as a way to examine the role of IT in organizations and within their key processes in the 1990s (Niehaves and Plattfaut, 2011). The introduction of innovative technologies has been often considered a key trigger of BPR projects, with authors discussing BPR as a key enabler for the introduction of enterprise systems (Chou and Chen, 2009), and a key moderating factor in increasing the value generated by ICT projects (Loukis et al., 2009).

Indeed, IT capabilities are considered important for determining business process performance, such as managerial capabilities at the process level (Ferraris et al., 2018). Notably, Chou and Chen (2009) emphasize the key role of advanced technology in enabling BPR for supply chain processes.

This kind of project is generally multidisciplinary in nature, and involves multiple stakeholders (Brown et al, 2011), where it is not only the cross-functional focus that is considered crucial, but also the involvement of different levels within the organization hierarchy and external actors (e.g., suppliers; customers; other organizations; Weerakkody et al., 2011).

The success of BPR projects is indeed considered dependent on employee involvement, as the direct involvement of employees can lead not only to bottom-up creative insights for process enhancements, but can also prevent the failure of BPR projects due to human resistance and underestimation of risk factors (Hengst, and Vreede, 2004; Weerakkody et al., 2011). Nevertheless, some scholars raise some arguments against these considerations, claiming that bottom-up approaches are costly and time-consuming (Brown et al., 2011). In summary, a collaborative BPR with the involvement of actors not only from inside the company, but also outside the company's boundaries, is considered necessary, but even more challenging (Niehaves and Plattfaut, 2011).

2.2.2 Challenges of adopting I4.0 technologies in SCM processes

Implementing I4.0 technology in SCM processes is a challenge for companies in all industries since it prompts deep changes in a company's organization, culture, supply chain configuration and even business model (Rüßmann et al., 2015, Pironti et al., 2018). Indeed, according to Lee et al. (2014; 2015), I4.0 extends beyond simple ICT integration in industrial manufacturing, as it must include transformations in organizations and their cultures. I4.0 implies the implementation of technological advances that, in some cases, are already used in the traditional manufacturing system in a way that gives birth to a fully integrated, automated, and optimized production flow (Wang et al., 2016). Further, I4.0 requires supply chains not only to adopt modern technologies and engage in capability development but also to transform their business models and network structures to achieve coherent vertical integration, and this is likely to change traditional relationships between supply chain actors and people working on these processes (Sanders et al., 2016). Indeed, Waller and Fawcett (2013) claim, with reference to big data analytics, that the changes introduced by this new I4.0 technology will not only intrinsically effect the way the supply chain processes are managed and designed, but will also call for new competences and professional profiles, thus strongly impacting human resources. Introducing such significant changes requires companies to be aware of the implications for their organization and their human resources, to prevent resistance and to be able to involve internal and external actors – in line with a BPR approach. In the I4.0 scenario, the management of the transformations connected to the adoption of such disruptive technologies requires a continuous collaboration between supply chain actors positioned at different levels (da Silva et al., 2019); this means that, from a research point of view, there is a need to adopt an integrated perspective when analysing this problem, involving all the actors in the supply chain who are directly involved in the process. This approach, however, has rarely been adopted in studies dealing with I4.0 and supply chain processes (e.g., Dallasega, 2018; Dalmarco and Barros, 2018).

3. Methodology: a case study with collaborative co-production of research

We decided to adopt a qualitative approach to exploring the research questions, through the mean of the case study method, a diffused research methodology for exploring BPR (e.g., Laurenza et al., 2018), SCM (e.g., Hofmann et al., 2018), and IT (e.g., Gunasekaran et al., 2018) related issues.

The case study research method is appropriate when the research question is asking "*How*" (Baxter and Jack, 2008), as it allows the inclusion of social processes and knowledge regarding managerial elements in the analysis, thus granting better knowledge and a more in-depth understanding of complex problems (Voss, 2010).

Case studies allow for the generation of a theoretical basis from the observation and analysis of actual organizational practices (Meredith, 1998), studied in their natural setting and supported by various sources of data (Yin, 2017). As this aspect is particularly important for our research problem, a co-production of research approach was put in place between academics and practitioners, to enable the collection of a broader and more in-depth set of data (Martin, 2010; Köhler et al., 2019).

4.1 Case characteristics

Toward this aim, we developed an illustrative case study focused on the construction industry. While there are already some manufacturing industries (such as electronics and fast-moving consumer goods) which are moving faster towards the adoption of I4.0 technologies in their processes, other industries are still lagging behind, and the diffusion rate of these tools is lower than anticipated, despite the great potentials (Lin et al., 2018). The construction sector falls within this category: despite great opportunities to adopt and introduce different I4.0 technologies to support plant operations (Dallasega et al., 2018), several companies are still far from an extensive adoption, due to the radical changes these innovations introduce to process execution (Kothman and Faber, 2016).

The company under analysis - pseudonymously named O&G - is an American engineering and construction company, with more than 50,000 employees worldwide, and a 2018 turnover of approximately 25 billion dollars. In 2017, the company was awarded a contract to support the realization of a big ethylene production plant in North America. A warehouse was designed and built near the construction plant to store and provide materials to support construction operations; the warehouse, directly owned by O&G, extends over a seven mile area and manages more than 5,000 different material categories.

For the purpose of our study, we focus our attention on a BPR project that, from December 2017 to February 2019, took place in this warehouse for the inbound materials receiving and the outbound materials support processes. The main aim of this initiative was to identify possible ways to improve these processes, with a particular focus on emerging technologies, thus making the case particularly interesting for the purpose of this study.

The inbound process includes all the activities related to on-site materials receiving and storage. The process starts when, one day in advance, the logistics provider confirms to O&G the arrival of the truck on-site the next day. Once arrived, the truck is first approached by a security guard, who directs the driver through the gate after carefully checking their identity. Once it has entered the site, the truck is directed to the waiting area, where it remains parked until a material coordinator arrives to check the contents of the trailer and the technical documents (and potential errors, e.g., the possibility that the truck has reached the wrong location), as well as compliance with site safety rules. Once the trailer has positively passed all the checkpoints, the material coordinator assigns the truckload to one of the site crews, usually composed of 4 or 5 material handlers. If the crew is already available, the truck is immediately escorted toward the unloading area; otherwise, the truck has to wait further and will be served according to a "first-in-first-out" rule. All the materials in the trailer are carefully unloaded and subjected to a damage inspection. In the case of evident damage or quality problem, a claim is immediately opened and the material reloaded onto the truck; in the case of uncertain damage, the material coordinators need to contact the customer's field engineers at the construction site for a more accurate assessment of the nature of the problem (e.g., by sending them pictures of the material for a virtual evaluation, or waiting for them to come to the warehouse for an in-person assessment). Once everything has been controlled and certified as suitable to support project activities, the truck can leave the site, with materials being stored in appropriate storage areas. The time spent by the truck at the warehouse site is the key indicator of this process, because O&G has negotiated a two hour limit with the logistics providers – this means that the company has to pay additional money for any extra time spent on site by the truck. The time of truck arrival and departure is recorded by the security guards at the entry and exit gates.

The outbound process includes all the activities related to managing the material requests coming from the construction site and preparing the trailer to be sent to the plant. The process is initiated by the customer's field engineers, who open material request orders that are immediately issued to the warehouse through an integrated Enterprise Resource Planning (ERP) system. These requests are rooted to material coordinators according to the type of material, who first evaluate them against the project activities progress; if the materials were requested too far in advance of the project work breakdown structure, they notify the main site to request the material at a closer date. If the request is time-legitimate, the material coordinators create a "pick ticket" to be assigned to a crew of material handlers. Once the ticket is created, a promised delivery date is also planned, which can vary according to the urgency of the request (the field engineers can classify the request as "urgent" when opening the order on the system). The crew will take care of this request as soon as possible, following the "first-in-first-out" rule; only when the request is really urgent will material coordinators ask the crew to serve it immediately. The first activity for material handlers consists of locating the requested materials on the site. This identification is manually made; both because information about material quantities are not updated in real-time, and because a physical verification is required to check the quality has not been compromised by outdoor storage, crew members need to walk through the storage area, be sure the materials are available in the requested quantity, and verify that every piece is still in good condition. In cases of uncertain damage, material coordinators are notified and need to contact field engineers to better assess the nature of the problem. If the requested quantity is present, the material handlers can start organizing the delivery activities, which means loading the trailer, transporting it to the staging area, and setting up the outbound delivery with the logistics provider. If instead, the quantity is not available, the material handlers notify the material coordinators, who will issue a purchase order to the suppliers of the missing materials – with the delivery managed through the inbound process already described.

The time needed to satisfy a material request is the key indicator of this process: O&G has a promised three day level of service for "urgent" requests, while standard requests should be managed within five days in the case of commodities, and 10 days are allowed for more complex materials. The opening and closure dates of the order request are tracked through the O&G system and can be accessed by both field engineers and material coordinators.

Table 1 reports the main actors involved in the process and their primary responsibilities.

< TABLE 1 >

In light of this description, this scope of analysis can be considered a suitable background against which to explore our research problem, for four reasons.

First, in the context of the execution of a construction project, materials management activities are one of the most constraining operations, since no construction activity can take place without materials, and requires the definition of appropriate managerial practices and the introduction of improvements to increase process performance.

Secondly, these two processes are characterized by a high level of integration, as they involve all the actors in the materials management supply chain supporting the project (i.e., the material suppliers, the logistics providers, the warehouse site operators, and the main plant operators), thus giving the opportunity to analyse a supply chain process from an integrated perspective.

Third, despite being mostly human-centric, these activities present many opportunities for technological support, which makes the case an interesting unit of analysis for our first research questions.

Finally, from a practical point of view, the construction industry relies on complex operations, which are organized to secure the health and safety of workers. Inducing radical process changes in such contexts thus needs careful analysis of workers' needs and potential risks, thus justifying the relevance of the context to our second research question.

4.2 Research design: a collaborative approach with process stakeholders

Many scholars propose that, if knowledge is to be relevant to management decision making, co-production by academics and practitioners can lead to stronger results, as close connections with practitioners can enable the collection of richer data by researchers (Martin, 2010; Kohler et al., 2019). In this spirit, the involvement of practitioners – particularly suitable in case study research – can range from providing data and information to leading, commissioning, and identifying research results (Antonacopoulou, 2010).

For this reason, in order to analyse the BPR initiative in our case, we opted for a co-production of research between academics and process actors and stakeholders, in all the steps of the process analysis, identification of criticalities and improvement, discussion and validation of interventions. This approach was considered suitable and applicable, in the context of BPR, for two reasons.

On one side, it is recognized that, in order to introduce process innovation and improvements, companies rely more and more on knowledge from different sources (Niehaves et al., 2011). Among the external sources, collaboration with universities has been recognized as an effective way to generate more creative and radical ideas (McCabe et al., 2016), given the mutual interest pushing the two parts to collaborate – potential knowledge creation from the university perspective, process benefits from the company perspective.

On the other side, the involvement of academics can facilitate the implementation of a bottom-up approach when introducing process improvements (Weerakkody et al., 2011), which is usually considered more effective in diffusing radical changes which affect the way people execute activities (Kim et al., 2014). Academics, in fact, can play a facilitator role in the phases of process assessment and the identification of potential improvements, driving objective and fair evidence by directly interaction with process stakeholders. Also, in this case, there is a mutual interest from both sides in implementing this type of approach: from the university perspective, there is the potential to obtain evidence and results which are confirmed and validated directly by process actors; from the company perspective, the benefits are in the diffusion of a bottom-up "culture" in BPR projects.

The research process involved four steps, briefly described below.

Step 1: Process characteristics - first-round interviews

First, the research team (comprised of one senior academic, two junior academics, and eight undergraduate students) conducted several interviews with all the actors reported in *Table 1*, with the purpose of collecting information about the nature of process activities, relationships between actors, the type of tools used, the competencies required for effective activities execution, and critical process aspects.

One truck driver, two security guards, four material coordinators, ten material handlers, and two field engineers were interviewed to obtain a complete view of both processes. After each interview, the information collected was shared and validated with the interviewees, and further documents and reports were requested so as to integrate data.

Step 2: Process analysis - Coding

After data was collected through preliminary interviews, the research team was able to realize a first assessment of the two processes. The model proposed by Rosemann and vom Brocke (2015) was used as a reference point in order to characterize the process components. This model characterizes business processes around six core elements, each one assessed through specific capability areas. The six elements and their meanings are reported in *Table 2.*

< TABLE 2 >

The evidence found for each process was shared with the interviewees to check the accuracy of consolidated information.

Step 3: Process improvement identification - Second round interviews

The research team organized a second round of interviews with the same actors involved in Step 1, in order to identify the potential improvements to be introduced in the process. Given that our research questions specifically deal with the impact of I4.0 technology on supply chain processes (and the organizational changes to be introduced to support their introduction), we designed a specific list model by combining evidence provided by Rüßmann et al. (2015), Kang et al. (2016), and Ardito et al. (2018), which includes the following I4.0 technology classes and related benefits (*Table 3*).

< TABLE 3 >

Each class of process actors was asked to rate (and elaborate), on a 1 – 5 scale (where 1 = not at all and 5 = definitely), the following aspects:

- How much each class of technologies, if introduced, would have contributed to improving how process activities are executed (thus improving process performance);
- How much each type of technologies, to be introduced effectively, would have required the redesign of organizational mechanisms (thus impacting the current organization and human resources).

Step 4: Data summary

With this information, the research team was able to synthesize the main evidence and provide, for each process, a ranking for each I4.0 technology class, both in terms of the potential impact on process execution and on the organization and human resources.

Step 5: Panel discussion

A final panel discussion was organized to discuss and validate the data provided, and explore and enrich the evidence coming from the case study. The panel discussion included the research team, the internal and external process actors involved in the previous steps of the analysis, as well as some company managers. In practice, new process technologies, as well as the investment needed, may introduce risk factors – connected to the actual adaptation of people to their usage and the necessary transition period to bring the process into full integration with activities – which may affect the achievement of potential benefits (Tupa et al., 2017). These issues are not evident from a single actor's perspective but can arise via managers, who have a more integrated view of the process.

For this reason, the research team presented the proposed technologies to management during this meeting, identified through interviews and data analysis, and asked that they discuss them in light of the potential risks connected to their introduction. The discussion was moderated by the research team in order to favour the convergence of manager evaluations.

4. Case analysis

This section provides the primary evidence from case data collection, coding, and analysis, according to the steps previously described.

During the first round of interviews, the main roles involved in the project provided information about the current process status. *Table 4* provides an overview of the inbound process, while *Table 5* describes the outbound process. In each table, the main process issues reported by the actors are also highlighted and numbered progressively (CI for criticalities in the inbound process – from 1 to 12 – and CO for the criticalities in the outbound – from 1 to 14).

< TABLE 4 >

< TABLE 5 >

For both processes, the main issues are related to the possibility of realizing the reliable planning of input volume (truck arrival and material requests) – which prevents an efficient allocation of resources – and in the low usage of technologies. Overall, this results in a poor process of strategic alignment, which affects the potential to optimize the process critical success factors (time needed to receive and unload the truck for the inbound process, and the time to satisfy a material request for the outbound process). For both processes, however, actors were found to be very collaborative both in dealing with communication issues and in finding ways to improve the functions of the current process, thanks also to management support.

During the second-round interview, the actors involved in the previous stage were asked to rate the different I4.0 technologies according to their potential impact on process performance and potential organizational and human resource impact. Thanks to the interviewees elaborations of the potential role and impact of the technologies, the research team was able to explain how each tool would have been able to overcome the criticalities highlighted in the first round. *Table 6* and *Table 7* report the scores assigned to the different alternatives.

< TABLE 6 >

< TABLE 7 >

In the outbound process especially, the process actors agree that a more extensive use of I4.0 technologies would provide consistent benefits for the execution of activities. Material coordinators and handlers, in particular, are those pushing for more "advanced" solutions: tools such as integrated applications, virtual assistants, simulation software, automated vehicles, robotics, and smart glasses, were all recognized as being key drivers for process performance improvement. As they also imply a radical change in the way activities are now executed, however, they also require the introduction of specific organizational mechanisms – which range from simple training for technology use to the establishment of new roles in the process. External process actors (i.e., truck drivers, security guards, field engineers) were somewhat more conservative in identifying the relevant technologies, but still aware of the potential connected to their introduction. External actors had more doubts about organizational impact of these changes, and the discussion of the implications of these new technologies prompted in-depth reflection for everyone regarding the "investment" needed to adapt their current way of executing activities (e.g., the use of software to schedule site arrival and to manage electronic documents through QR codes for the truck drivers; the use of software on a tablet to record truck arrival and departure activities for the security guards; or the use of simulation software and smart glasses to help the warehouse site to solve technical problems for field engineers).

Finally, the panel discussion helped to combine the previous evidence with considerations about the level of risk associated with the introduction of each class of technology, defined as the organizational variability in assimilating technology, which may prevent full achievement of the potential benefits.

Table 8 summarizes the final results, in which the assessment of the various I4.0 technologies is enriched with an evaluation of the risk connected to their implementation, including the middle and top management perspectives.

< TABLE 8 >

Technologies belonging to the "*smart tracking sensors*" class were considered at low risk, as the current processes are already exposed to this type of tool, despite requiring the adoption of more state-of-the-art solutions. Technologies such as "*Augmented reality*" (and, to some extent, "*Cloud manufacturing and IoT*") - despite the radical changes they introduce in executing process activities - require a fast and full understanding of their functionalities to obtain benefits from their implementation and, when it is not the case, their adoption can lead to a deterioration in process performance – at least in the short term.

5. Discussion of findings

Thanks to the information collected through the case, we are able to summarize the main case findings in *Figure 1*, which contributes to the discussion about the role of I4.0 technologies in supporting supply chain processes, including all the variables identified as relevant in the literature and by practitioners (i.e., process and organizational impact, and level of risk).

< FIGURE 1 >

5.1 I4.0 technologies support to SCM

The primary objective of our research is to discuss the role I4.0 technologies can play in supporting supply chain processes.

If we look at the positioning on the horizontal axis resulting from case data collection and analysis, we can see that process actors associate all of the proposed technologies with a medium-high contribution to the improvement of process activities execution (with an average score higher than 3.5 for both the inbound and the outbound process).

There is particularly a shared view about the role of "*Cloud manufacturing and IoT"* and "*Smart tracking sensors"* in solving process criticalities such as lack of planning and the establishment of standard procedures, difficulties in coordination and communication between process actors, and the weak automation of physical activities. Thanks to the bottom-up approach adopted, these evaluations are provided directly by the actors involved in the process, and are therefore strictly connected to the process execution.

This result is in line with the diffusion curve of I4.0 technologies, which presents these solutions as the most “mature” in the SCM field, thus making the assessment of their benefits easier, compared to the more "pioneering" ones (Klitou et al., 2017; Dalmarco and Barros, 2018).

These findings, despite coming from the analysis of a specific supply chain process in a particular context (i.e., materials management in construction), can be generalized to all the supply chain processes with, as a critical success factor, pressure on time. The actors involved in this discussion are different nodes of a broader and complex network which supports an integrated physical flow, in which the warehouse represents the decoupling point between the inbound and outbound phase, and information sharing, effective communication, and collaboration are core aspects of the successful functioning of the supply chain process.

In this scenario, technologies such as smart sensors for scanning materials onto the trailer and tracking on site, cloud computing for realizing integrated software, and tools for executing activities (such as drones and automated vehicles), are the best way to introduce new I4.0 solutions with the most significant impact on time performance (Chou and Chen, 2009), and this characterization of the context can demonstrate the applicability of the technology to other areas of a process that share the same features.

5.3 The impact of I4.0 technologies on an organization

A look at the distribution of the technologies along the vertical axis provides some interesting insights for our second research question about the consequences of I4.0 technology on an organization and on human resources.

"Augmented reality", and "*Smart tracking sensors",* are estimated to have the most intense organizational impact, connected to the establishment of new roles (involving technical knowledge of the technology, so as to provide support in case of problems), and investment in ad-hoc training initiatives to support the development of new competencies for the better use of these tools. Even if still present, these aspects are less emphasized for other technologies. New roles are also required to support "*Big data and analytics"* and "*Cloud manufacturing and the IoT"* option, but in these cases the organizational impact is more limited, as these roles are more independent from a process perspective, and asked to support pure back-office data analysis in one case, or to take full responsibility for some activities in another (e.g., receiving trucks, management of urgent requests).

A more in-depth look at the scores given when assessing the organizational impact reveals that when evaluating the adoption of new technological solutions to support processes, the main concerns are mostly from external actors.

In technology-driven BPR projects, the human impact is a key determinant of the success of such initiatives (Hengst, and Vreede, 2004; Niehaves and Plattfaut, 2011); our evidence emphasizes the importance of the collaborative BPR perspective in order to span the boundaries of the single organization to achieve an engaged consensus on the expected benefits of the new solutions for process management, considering proper support to overcome possible organizational resistance.

Our work thus provides interesting insights into the importance of assessing such projects as regards both process-related aspects and the impact on the organization from actors who will be the primary users of the technologies.

If the actors involved in the process provide a practical and short-term point of view in the evaluation, then the managerial point of view completes the picture, applying a more long-term assessment of the risk connected with the speed of assimilation of the new solutions within the organization. The solutions judged as less risky (i.e., "C*loud manufacturing and IoT"* and *"Smart tracking sensors"*) are those for which management is confident of a quick - and not disruptive – assimilation from an organizational point of view (Lee et al., 2015).

6. Conclusions: main contributions and future research directions

This study explored the role of I4.0 technology in improving process management in the supply chain. In order to do so, we used a case study focused on the inbound and outbound material management processes supporting a construction project, and assessed the benefits and impact of I4.0 by discussing them directly with internal and external process actors, using a bottom-up logic, in the spirit of collaboration between academics and practitioners.

6.1 Contribution to research

The contribution of our findings is at the intersection of the BPR and SCM research fields.

On the SCM side, the analysed case enriches the discussion about the role of I4.0 technologies in supporting supply chain processes and sheds light on how to address the peculiarities of the construction industry when introducing process changes linked to the adoption of industry 4.0 technologies.

As discussed, supply chain digitalization is a trend that is more and more commonly debated in the literature (e.g., Meier, 2016), and our evidence supports the idea that a reasoned introduction of these technologies, accompanied by an appropriate assessment of the organizational aspects to be redesigned to support them, can only result in an overall improvement of supply chain performance (and the satisfaction of the process actors). In this vein, we are addressing one of the key steps in the triadic framework by Büyüközkan, and Göçer (2018) to effectively develop a digital supply chain. Our findings support the crucial role of the effective integration of humans and technology in the form of workforce engagement and mutual adaptation between workforce and technology. These aspects, according to Büyüközkan, and Göçer (2018), should be part of the goal of developing a digital supply chain, so that the novel technologies are not counterproductive.

When it comes to Industry 4.0 scenario in particular, studies (e.g., Da Silva et al., 2019) infer that several changes can be foreseen for companies and supply chains, given the plethora of possibilities opened up by information richness and visibility. We have taken initial steps in our case study by moving from theory to practice in the analyses of changes that are occurring very rapidly in several industries.

Notably, in analysing the construction industry, we have answered the call by Dallasega et al. (2019) to help to better understand the potential of Industry 4.0 technologies to address the challenges of the construction supply chain related to flows synchronization and the avoidance of expensive stoppages along the processes.

We also support all those scholars promoting the value of using a bottom-up approach when implementing BPR projects (e.g., Niehaves and Plattfaut, 2011), as we demonstrate that a process actor-driven analysis can provide a clearer view of process criticalities and identification of the pros and cons of the different lines of improvement (in our case, the I4.0 technology classes). Moreover, we provide an example of a collaborative business engineering (CBE) approach applied to BPR, which can help to address poor stakeholder involvement as one of the key reasons for the failure of BPR projects (Hengst, and Vreede, 2004).

The approach adopted to assess the I4.0 technologies is indeed cross-functional, extends to different supply chain actors and includes various levels in the organizational hierarchy, thus providing guidelines for the change in traditional relationships between supply chain actors and people working on the processes (Sanders et al., 2016).

Lastly, the design of a research coproduction study reconfirms the relevance of external collaborations in the identification of process innovation, with particular reference to the university-industry relationship (McCabe et al., 2016).

6.2 Contribution to practice

This study makes three main contributions for practitioners.

From a theoretical perspective, it shows the application – and connection – of two relevant frameworks, for process analysis and I4.0 technologies, which are presented in their main components and definition. By providing this view, we are contributing to the need, expressed by Büyüközkan, and Göçer (2018) to develop guidelines to aid managers in deploying digital supply chains. With the awareness that this deployment passes through important changes in processes and management practices, we have analysed the impacts of such changes from the point of view of different actors involved in the processes under investigation.

From a methodological perspective, our study provides a detailed description of the process to manage a technology-driven BPR project, demonstrating the value of directly involving the process actors in the different phases.

From a findings perspective, it positions the different technologies according to their potential impact on process execution, organization, and level of risk, thus giving managers an ex-ante view of I4.0 solutions in the process of evaluating their introduction.

6.3 Limitations and future developments

Although the in-depth investigation of the topic through a single case study is considered of pivotal value for the present work, there are some limitations to be pointed out.

First of all, despite the richness and multi-perspective nature of the data collected and analysed, results are limited to a single case, thus exposing the study to the problem of generalisability of the results. Although the case could be considered representative of companies of similar dimensions, which are part of a rather complex network of actors that manage an integrated physical flow with a pressure on time, future research can use our findings as a basis to develop studies on a larger scale (e.g., surveys), in order to test the relationships between technology, organization, and performance from a statistical perspective.

Although the case analysis was performed longitudinally for over a year, the focus of our work is on the analytical phase that supports the reengineering of the processes, not the change management phase. Future research could study the empirical evidence coming from the introduction of the I4.0 technologies in the process, and discuss the differences between the planned impact and the actual impact.

Finally, the construction industry served as an interesting context for the study, as here supply chain collaboration is at its utmost. Future studies might focus instead on industries with characteristics of either high vertical integration or fragmentation with a confrontational-oriented, rather than collaboration-oriented, dominant approach.

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Table 1. Process characteristics: actors, activities, and performance

	Truck driver	*Security guards*	*Material coordinators*	*Material handlers*	*Field engineers*	
Type of actor	External	External	Internal	Internal	External	*Main performance indicator*
Main activities in the inbound process	Deliver materials to the warehouse	Receive truck on site; Record truck arrival and departure time	Check truck driver compliance with site safety and delivery location rules; Coordinate with field engineers; Coordinate truck unloading and departure	Manage truck unloading; Check material quality		Time spent by the truck on the site (2-hour limit)
Main activities in the outbound process	Take materials from the warehouse; Deliver materials to the main site		Filter and distribute material requests to material handlers; Coordinate with field engineers	Flag items to be delivered to the construction site; Pick up items to be delivered	Request materials; establish request priorities	Time to manage a material request (3-days for "urgent"; 5-10 days for "standard")

Table 2. Core elements of business processes (adapted from Rosemann and van Brocke, 2015)

Element	Definition
Strategic alignment	How much the process is aligned with the overall organization strategy
Governance	How far the process role and responsibilities are precisely defined
Methods	The way in which specific tools and techniques to support process activities execution are used
Information technology	How IT solutions are used to facilitate and better support process activities execution
People	How closely people skills and capabilities are aligned with process activities (and the identification of potential improvements)
Culture	How the process contributes to the establishment of a process – centred organization culture

Table 3. Main classes of I4.0 technologies and related benefits

	Definition	Main benefits
Cloud manufacturing and Internet of things	Cloud manufacturing is the process of utilizing well-established manufacturing resources, such as Enterprise Resource Planning (ERP), through the cloud. This way, the information can be viewed, updated and applied at any time or place. It can take many different forms such as cloud computing, virtualization, and the Internet of Things.	Support real-time data collection about production and inventory levels, which allows the supply chain to act in a predictive manner to the challenges of a volatile market, but also the improvement of operational performance through effective management of production activities
Augmented reality	Interactive experience of a real-world environment where the objects that reside in the manufacturing system are "augmented" by computer-generated perceptual information in order to simulate future events	Supports a reduction in excess product that quickly loses value, faster response to changing client requests or supplier availability, and better optimization of shipments and the assurance of complete deliveries
Smart tracking sensors	Sensors with intelligence capabilities to enable information processing, communication, and self-adaptation functions	Support traceability of each item and generation of highly visible supply chains, where the location of all the elements could be ascertained at any point in time
Big data and analytics	The use of machine learning and artificial intelligence techniques to process and extract information from diverse datasets for prediction and modeling	Support of machine-enabled decisions with minimum human intervention, thus improving the timing and the depth of these decisions

Table 4. Characteristics of the materials management inbound process (*= codes for the detected critical issues)

	Truck driver		Security guard		Material coordinators		Material handlers	
Strategic alignment	*Not ranked due to partial involvement in the process*		*Not ranked due to partial involvement in the process*		TO BE IMPROVED	Planning is weak (a "reactive" approach is used); performance is not extensively measured; a clear process view is absent. (CI1*)	TO BE IMPROVED	Poor planning, which generates variability in crew activities and in the overall outcome (CI2)
Governance	TO BE IMPROVED	Different interface every time (CI3)	GOOD	Ability to report to material coordinators in case of problems	GOOD	Act as the only reference point to define standard process practices and provide input for improvements (especially for unload, quality control, and storage activities)	GOOD	Material coordinators act as the only reference point to define standard process practices and provide input for improvements (especially for unload, quality control, and storage activities)
Methods	GOOD	Checklist for material site delivery is communicated in advance	GOOD	Specific procedures for security check are defined and must be followed	TO BE IMPROVED	Some procedures for material receiving and quality control are defined, but do not include adjustments needed because of daily variability in the material inbound volume (CI4)	TO BE IMPROVED	Some procedures for material receiving and quality control are defined, but do not include adjustments needed because of daily variability in the material inbound volume (CI5)

IT	TO BE IMPROVED	Delivery documents are paper-based (CI6)	TO BE IMPROVED	Truck driver information and arrival/departure times are manually recorded (CI7)	TO BE IMPROVED	Materials data is managed in the ERP; planning of crews is Excel-based (CI8)	TO BE IMPROVED	Materials data is managed in the ERP; planning of crews is Excel-based (CI9)
People	TO BE IMPROVED	Poor communication with the warehouse site before and during the visit (CI10)	GOOD	Easy communication with material coordinators, and good responsiveness in case of problems	TO BE IMPROVED	Poor communication with the logistics provider before the visit; good internal communication to plan and allocate crews; crew members technical competences are complete (CI11)	TO BE IMPROVED	Good communication with the material coordinators to plan activities; improvable communication with other actors when trucks are on site; complete competences to execute activities (CI12)
Culture	GOOD	The process has many improvement opportunities, and managers are open to listening and implementing process improvements	GOOD	The process has many improvement opportunities, and managers are working toward the identification and implementation of process improvements	GOOD	The process has many improvement opportunities, and managers are open to listening to (and implementing) suggestions and input from material coordinators and handlers	GOOD	The process has many improvement opportunities, and managers are open to listening to (and implementing) suggestions and input from material coordinators and handlers

Table 5. Characteristics of the materials management outbound process (*= codes for the detected critical issues)

		Field engineers		Material coordinators		Material handlers
Strategic alignment	TO BE IMPROVED	The delivery time is not always respected (especially for "urgent" requests), and sometimes there is lack of understanding of project needs by the warehouse (CO1*)	TO BE IMPROVED	A large number of "urgent" requests are received daily, making material handler planning very difficult; process performance is not measured by distinguishing the nature of the request (CO2)	TO BE IMPROVED	Planning is weak, especially because of the difficulty in predicting requests in advance; this generates variability in the daily volume of material handler activities, and in the time needed to manage these requests (CO3)
Governance	GOOD	Material coordinators act as the only interface and reference in case of problems or specific requests; project managers act as the point of contact for more technical aspects	TO BE IMPROVED	Difficulties in establishing standard process practices and input for improvements, as material coordinators mainly interact with field engineers, who have low managerial responsibilities, and project managers are not responsive (CO4)	TO BE IMPROVED	Material coordinators act as a reference point to define standard process practices and input for improvements, but some technical aspects related to material management require more involvement from field engineers (CO5)
Methods	TO BE IMPROVED	No criteria are used to classify "urgent" material requests; difficult to access the real progress status of the material request (CO6)	TO BE IMPROVED	No criteria are used to classify "urgent" material request, with frequent changes of the priority status; difficulty in establishing standard procedures for materials check, given the high variability in demands from the main site (CO7)	TO BE IMPROVED	The procedures for materials checks are often overruled according to the priority status (or the change in status) of material requests (CO8)

IT	TO BE IMPROVED	Material request creation is managed through ERP; no IT support is used to provide a real-time update regarding how the request is being managed in the warehouse (CO9)	TO BE IMPROVED	Material request creation is managed through ERP; no IT support is used for material management activities (CO10)	TO BE IMPROVED	No IT support is used for material management activities (CO11)
People	TO BE IMPROVED	Material coordinators do their best to meet main site requests, but often communication and problem solving is an issue (CO12)	TO BE IMPROVED	Field engineers are responsive in case of problems, but provide limited support in dealing with project-related managerial aspects; some technical aspects related to materials quality check fall outside material handlers' competences (CO13)	TO BE IMPROVED	Some technical aspects related to materials quality check (e.g., evaluation of damage entity; assessment of dimensions and tolerance) are difficult to self-evaluate (CO14)
Culture	GOOD	The process has many improvement opportunities, and managers are working toward the identification and implementation of process improvements	GOOD	The process has many improvement opportunities, and managers are working toward the identification and implementation of process improvements	GOOD	The process has many improvement opportunities, and managers are open to listening to (and implementing) suggestions and input from material coordinators and handlers

Table 6. I4.0 technologies impact on the materials management inbound process (1 = Very Low; 5 = Very High)

		Truck driver	Security	Material coordinators	Material handlers		
		Rating				***Main comments***	***Addressed criticalities***
Cloud manufacturing and Internet of Things	*Contribution to process improvement*	3	3	5	3	• Integrated software for truck arrival scheduling, material handler activities planning and on-site allocation • Real-time registration of truck arrival and departure • Cloud sharing of delivery documents	CI1, CI2, CI6, CI7, CI8, CI9
	Organizational impact	3	2	4	3	• Definition of a specific role dedicated to receiving trucks, wait management and owner of the data collection process • Collaboration with logistic providers to integrate the new software into their processes • Training to understand the correct use of technology	CI1, CI2, CI3, CI10, CI11, CI12
Augmented reality	*Contribution to process improvement*	1	3	4	5	• Smart glasses for material quality control • Robotics for material storage • Automated scanning systems	CI4, CI5
	Organizational impact	4	4	4	5	• Reference role for a reactive response in case of problems experienced in the use of the tools • Training to understand the correct use of technology	CI4, CI5

Smart tracking sensors	*Contribution to process improvement*	3	4	5	3	• QR code to scan and track delivery documents • Smart and weather resistant sensors for real-time material tracking and tracing	CI4, CI5, CI7, CI8, CI9
	Organizational impact	3	2	2	3	• Training to understand the new process functioning in light of the use of more real-time tracking systems (especially for logistics providers and material handlers)	CI4, CI5
Big data and analytics	*Contribution to process improvement*	2	3	5	4	• Analytical software to analyse data collected in more depth (e.g., truck arrival, departure, time spent serving trucks, quality problems) to enable better planning and problem solving	CI1, CI2, CI10, CI11, CI12
	Organizational impact	2	3	3	2	• Definition of a specific role dedicated to data analysis • Training to understand the correct use of technology	CI1, CI2, CI10, CI11, CI12

Table 7. I4.0 technologies impact for the materials management outbound process (1 = Very Low; 5 = Very High)

		Field engineers	**Material coordinators**	**Material handlers**		
		Rating			***Main comments***	***Addressed criticalities***
Cloud manufacturing and Internet of Things	*Contribution to process improvement*	5	5	5	• Integrated software for material request management • Virtual assistant for material inventory check • Drones for material location • Automated guided vehicles for material picking	CO2, CO6; CO7; CO8; CO9; CO10; CO11
	Organizational impact	4	5	5	• Establishment of a continuous communication channel with field engineers • Clear criteria for "urgent" request • Training to understand the correct use of technology • Reference role for a reactive response in case of problems experienced in the usage of the tools	CO1; CO6; CO7; CO8; CO13
Augmented reality	*Contribution to process improvement*	3	4	5	• Motion capture systems to monitor operator stress • Smart glasses for material quality control • Simulation tools to analyse material integration on the main site	CO2; CO14
	Organizational impact	4	5	5	• Establishment of a continuous communication channel with field engineers	CO1; CO4; CO5; CO12

					• Training to understand the correct use of technology • Reference role for a reactive response in case of problems experienced in the use of the tools	
Smart tracking sensors	*Contribution to process improvement*	4	4	4	• Smart and weather resistant sensors for easier material location	CO6; CO7; CO8; CO9; CO10; CO11
	Organizational impact	2	3	3	• Training to understand the new process functioning in light of the usage of more real-time tracking systems (especially for material handlers)	CO8; CO9; CO10; CO11
Big data and analytics	*Contribution to process improvement*	4	5	3	• Analytical software to analyse data collection more in-depth (e.g., urgent vs. standard material request, inventory status, time to manage the request) to enable better planning and problem solving	CO2; CO3; CO9; CO10; CO11
	Organizational impact	4	3	2	• Collaboration with the main site for data sharing and analysis • Training to understand the correct use of technology • Definition of a specific role dedicated to data analysis	CO9; CO10; CO11

Table 8. Summary of I4.0 technology characteristics (*numerical scores obtained by averaging values in Tables 6 and 7*)

	Potential impact on process improvement		**Potential impact on the organization and human resources**		**Level of risk**
	Inbound	*Outbound*	*Inbound*	*Outbound*	
Cloud manufacturing and Internet of Things	3.5	5	3.00	4.67	Medium
Augmented reality	3.25	4	4.25	4.67	High
Smart tracking sensors	3.75	4	2.50	2.67	Low
Big data and analytics	3.5	4	2.50	3.00	Medium

Figure 1. Classification of I4.0 technologies (*numerical scores obtained from Table 8; size of the bubbles representative of the level of risk*)