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Implementation of digital manufacturing technologies: Antecedents and consequences

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ABSTRACT

The use of digital manufacturing technologies (DMTs) is changing the face of the manufacturing landscape and enhancing the competitiveness of firms. However, its implementation is still a relatively unexplored phenomenon and demands attention. The purpose of this study is to determine the role played by technological context, organizational context, and environmental context of firms in the implementation of the DMTs. A hypothesized model is proposed and tested using survey-based data from the International Manufacturing Strategy Survey VI comprising 931 firms across developed and developing countries. The proposed research model gains support from the technology–organization–environment framework and the combinatorial technology evolution theory, which together provide a holistic understanding of the technology implementation process in terms of its enablers and performance outcomes. We find that although the organizational context and environmental context impact DMTs' implementation, these impacts are mediated through the technological context of the firm. Moreover, the implementation of these technologies has a significant impact on firm performance in terms of flexibility, design, delivery, and quality performance. Contributing to the empirical research gap in the domain of DMTs' implementation, this study also generates insights for practitioners about the complementarity of the technological, organizational, and environmental factors that together enable the implementation of DMTs and enhance firm performance.

1. Introduction

The rapid diffusion of industry 4.0, powered by digital technologies has gained widespread attention among both academia and industry (Castelo-Branco et al., 2019; Kamble et al., 2018). With the increasing use of these digital technologies, the business environment is progressively becoming competitive. Hence, firms are in a constant struggle of improving their production processes, retaining their market shares, and surviving the competition in a cost-effective manner (Vinodh et al., 2009). Moreover, today's consumers have become well informed owing to technological advancements, thereby raising the demand for economical and personalized products with high quality and shorter lead times (Horváth and Szabó, 2019). To meet these demands, firms need to develop their production systems by leveraging new manufacturing technologies. In this realm, the use of digital manufacturing technologies (DMTs) is a wise choice that comes with the promise of efficiency, flexibility, cost-effectiveness, speed, and enhanced customization (Dalenogare et al., 2018; Hofmann and Rüsch, 2017). Based on the principles of connectivity, automation, integration, and computation (Brettel et al., 2014), the DMTs transform traditional factories into smart ones (Agrifoglio et al., 2017; Battaïa et al., 2018). This is evident in the country-level initiatives, such as Germany's "High Tech Strategy 2020," China's "Made in China 2025," America's "Advanced Manufacturing Partnership," and Brazil's "Towards Industry 4.0," to name a few (Dalenogare et al., 2018).

Although the research on digital manufacturing and industry 4.0 is still in the early stages, several studies have explored the phenomena from different perspectives, as shown in Appendix A1. Some of these studies explore digital manufacturing in relation to servitization (Cenamor et al., 2017; Frank et al., 2019b), lean production (Buer et al., 2018; Tortorella and Fettermann, 2018), and logistics management (Hofmann and Rüsch, 2017; Holmström and Partanen, 2014). While other studies explore the type of technologies (Oztemel and Gursev, 2018; Strozzi et al., 2017), their implementation (Bibby and Dehe, 2018;

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Horváth and Szabó, 2019), and performance outcomes (Dalenogare et al., 2018; Moeuf et al., 2018). This study focuses on the implementation aspects and tries to unveil the enablers. Further, it examines the performance implications that these technologies have for manufacturing organizations.

There is a lack of understanding of the factors that enable the implementation of DMTs. The complex nature of these technologies makes their implementation phenomenon a subject of research (Frank et al., 2019a). In their study, Frank et al. (2019a) propose a sequential adoption pattern of digital technologies, where the front-end technologies are dependent on the base technologies[1]. The authors do not explore the factors that enable the implementation of these technologies, though it is reported that the firms, in general, face challenges in the implementation of industry 4.0 technologies (Frank et al., 2019a). Strozzi et al. (2017) identify the need for implementation frameworks for smart factories and posit that previous studies have not done much justice to the study of organizational aspects of DMTs' implementation. Zangiacomi et al. (2017) state that technology implementation is a complex and difficult phenomenon and a lack of understanding of the intricacies involved in it can lead to failed implementations. Similarly, within the practitioner literature, a survey conducted by McKinsey on the use of digital manufacturing demonstrated that manufacturing firms were aware of the importance of digital manufacturing yet faced high uncertainty regarding the implementation process and its requirements (Breunig et al., 2016).

Similarly, another important element is the lack of trust and uncertainty on the benefits of implementing digital technologies (Holmström et al., 2017; Dalenogare et al., 2018; Frank et al., 2019a). The role and the implications of digital technologies in improving performance outcomes of firms need to be better understood (Moeuf et al., 2018; Dalenogare et al., 2018). Establishing the benefits of DMTs for the production process will enhance the confidence and commitment of managers in these technologies and their implementation. Hence, both the aspects of implementation enablers and performance outcomes go hand in hand and provide a better understanding of the phenomenon. Therefore, keeping in view that identification of the enablers for DMTs' implementation is an important and understudied domain, and considering the lack of research in relation to DMTs' performance implications, this study aims to address the following research questions:

RQ1. *What are the different antecedents that enable the implementation of DMTs?*

RQ2. *What are the different performance outcomes that can be achieved by implementing DMTs?*

We aim to address these questions by using technology–organization–environment (TOE) framework (Depietro et al., 1990), which identifies different enabling contexts, their interplay, and role in the implementation of DMTs, as well as the various performance outcomes achieved by implementing DMTs. (Depietro et al., 1990). The study also uses the combinatorial technology evolution (CTE) theory (Arthur, 2009), which comprises three processes, namely, "demand," "combination," and "success". The CTE theory provides explanatory power to support how successful implementation of technologies results in improved performance outcomes of firms.

We test the proposed model using global data from the sixth round of the International Manufacturing Strategy Survey (IMSS VI), which incorporates data from manufacturing firms of developed and developing countries. Structured equation modeling is used for hypotheses testing. The contributions of this study are four-fold. First, the study proposes a specific interplay of the TOE contexts that are applicable for DMTs' implementation. Second, unlike previous research, the three processes of CTE, namely the "demand," "combination," and "success" processes, have been explicitly highlighted and utilized in this research. Third, the research statistically determines the factors and their interplay that enable DMTs' implementation. Last, the study also empirically endorses the performance implications of DMTs.

The remainder of this paper is organized as follows. Section 2 provides a literature review about DMTs' implementation, TOE framework, and the theoretical lens used for hypotheses generation. Section 3 presents the research model and hypotheses, and section 4 details the research methodology used as well as the analyses and results. Section 5 provides a discussion on the results followed by theoretical and managerial implications while section 6 highlights the limitations of the study and future research directions.

2. Literature review

2.1. Implementation of digital manufacturing technologies

The extant literature on digital manufacturing is descriptive in nature and focuses on providing an overview of DMTs (Strozzi et al., 2017; Oztemel and Gursev, 2018), current status and future directions for research in this domain (Hofmann and Rüsch, 2017; Liao et al., 2017; Buer et al., 2018; Kusiak, 2018), and the implementation of these technologies in organizations (Bokrantz et al., 2017; Kamble et al., 2018; Li, 2018a; Xu et al., 2018). Other studies concern general concepts relevant to digital manufacturing such as its evolution (Yin et al., 2018) and its benefits to innovation (Svahn et al., 2017; Reischauer, 2018), lean production (Buer et al., 2018; Tortorella and Fettermann, 2018), and servitization (Cenamor et al., 2017; Rymaszewska et al., 2017). In addition to these descriptive studies, a few empirical studies explore the impact of different DMTs on the capabilities and performance of firms (Dalenogare et al., 2018; Moeuf et al., 2018; Szalavetz, 2019). A representative sample of the extant literature on digital manufacturing is provided in Appendix A1, illustrating the topic, authors, journal, research method, and findings of each study.

The implementation of DMTs and realization of digital manufacturing is an important topic of study. The existing studies mostly refer to the enabling technologies (Liao et al., 2017; Xu et al., 2018) necessary for the realization of digital manufacturing and miss out on the complementary support systems that are required to leverage the use of DMTs. Kamble et al. (2018) in their analytical study on the adoption of DMTs identify employee skills, cost, organizational and process changes, and lack of strategy as the main barriers to DMTs' adoption. Xu et al. (2018) identify the different technological and architectural requirements that enable digital manufacturing. Bokrantz et al. (2017) identify different enabling factors that facilitate the realization of digital manufacturing; however, the scope of their study is confined to maintenance organizations. Frank et al. (2019a) explore the implementation pattern of digital technologies in manufacturing whereas Gattullo et al. (2019) conduct a case study to propose a method for augmented reality-based documentation in industry 4.0. Although these studies provide useful insights into the different implementation aspects of digital manufacturing, none of them provide a holistic understanding of the implementation process. These studies neither empirically determine the enabling factors nor explain the interplay of different enablers in the implementation of DMTs, which is a research gap that needs to be addressed (Breunig et al., 2016; Dalenogare et al., 2018; Farooq et al., 2017; Frank et al., 2019a; Müller et al., 2018).

2.2. The Technology-Organization-Environment framework

The technology adoption literature has repeatedly used two renowned theoretical frameworks to understand the antecedents of adoption and implementation of new technologies. These two are the

[1] Front-end technologies represent the major dimensions of industry 4.0, such as smart manufacturing, smart work, smart product, and smart supply chain. Base technologies represent the technologies that provide connectivity and intelligence to the front-end technologies.

Rogers diffusion of innovation (DOI) theory (Rogers, 1983) and Depietro's TOE framework (Depietro et al., 1990). The DOI theory posits that a firm's technology adoption is dependent on its organizational and innovation characteristics, while the TOE framework proposes that three independent and complementary contexts—technological context (TC), organizational context (OC), and environmental context (EC)—facilitate technology adoption in organizations (Depietro et al., 1990). These contexts interact to create a unique situation that enables the adoption and effective deployment of technologies in the organization (Wang et al., 2010; Lin, 2014). Researchers have been skeptical about the validity of DOI while studying complex technological adoptions as DOI does not incorporate the external environmental factors that act as drivers for the technology implementation (Alshamaila et al., 2013; Wang and Lo, 2016). Therefore, the EC in the TOE framework provides it with a substantial advantage over the DOI because the environmental factors play an essential role and may enable or inhibit technology adoption decisions (Hsu et al., 2014; Masood and Egger, 2019).

The widespread use of the TOE framework is due to its completeness and flexibility to incorporate different factors in accordance with different technologies under study (Zhu and Kraemer, 2005). The three contexts of the TOE framework, that is, technological, organizational, and environmental context, incorporate various dimensions and factors that impact technology adoption (as shown in Appendix A2). The TC of an organization relates to "the internal and external technologies relevant to a firm" (Depietro et al., 1990). The OC represents "characteristics and resources of the firm, including linking structures between employees, intrafirm communication processes, firm size and amount of slack resources" (Depietro et al., 1990). The EC describes "the arena in which a firm conducts its business: its industry, competitors, and dealings with the government" (Depietro et al., 1990). These contexts may provide a unique set of strategic enablers that aid in the implementation of a certain technology. The three complementary contexts provided by the TOE framework seem relevant in the domain of DMTs, and thus, may lend power to conduct empirical (and perhaps conceptual) work in investigating the implementation of DMTs.

2.3. Combinatorial Technology Evolution and technology implementation

The CTE postulates that the existence of new technologies is dependent on previously existing technologies and processes and that the new technologies have some inherent properties of the old technologies. The theory states two mechanisms of technology evolution, namely, "combination" and "demand." The combination of existing technologies to form new ones will only be meaningful if there exists some need for new technologies. The new technologies need new arrangements, such as new organizational forms and capabilities, which supplement the use of new technologies (Arthur, 2009).

Studies have used CTE to explain how new technologies and innovations are based on previous technologies and how different combinations can lead to new avenues of value creation. For example, Holmström and Partanen (2014) use CTE in explaining the creation of new supply chain management solutions in the context of complex products resulting from the combination of digital manufacturing, equipment, and logistics. Similarly, Youn et al. (2015) show that during exploration, new technologies are created by combining old ones, and during exploitation, the technologies are modified from the existing combinations. Furthermore, Yoo et al. (2012) posit that the emergence of new products and services is enabled by the combination of digital artefacts and modules as explained by the CTE. These studies manifest the use of CTE in explaining the evolution of new technologies and knowledge, which combine and coexist to create new mechanisms of value creation.

2.4. TOE framework and CTE theory

The TOE framework and CTE theory together provide a holistic understanding of the technology adoption phenomenon. The enabling contexts of TOE help in defining the constructs while the CTE theory aids in explaining the underlying mechanism for technology adoption. The TOE framework posits that the technological, organizational, and EC impact the technology adoption process of a firm (Depietro et al., 1990). These contexts are well aligned with the "demand" and "combination" elements of CTE, and provide a comprehensive explanation and understanding of the new technology adoption in a firm. The EC from TOE represents the business environment in which the firm functions and is aligned with the "demand" aspect of CTE, which depicts the need for new technologies. Similarly, the TC and OC of the TOE are aligned with the "combination" aspect of CTE and posits that the combination of (organizational) processes and technology plays a vital role in new technology adoption (Arthur, 2009). The existing processes and technologies act as support mechanisms and provide the requisite infrastructure for the proper functioning of new technologies (Das and Jayaram, 2003; Frank et al., 2019a; Teece, 1996). The OC represents work practices and processes, while the TC represents the existing technologies. The appropriate combination of work practices, organizational processes, and existing technologies act as support mechanisms and aid in leveraging the potential of new technologies (Breunig et al., 2016; Lee et al., 2018). The "success" element of the CTE is manifested in the performance outcomes of new technology adoption. Hence, the complementarity between the TOE framework and CTE theory provides a comprehensive and holistic understanding of the complete technology adoption process, that is, the identification of enabling factors, the interplay of these factors for technology adoption, and the performance implications of new technologies.

3. Research model and hypotheses

3.1. Organizational context and technological context

Firms with a sophisticated TC require a certain work organization that complements the use of existing technologies (Yin et al., 2018). This study uses *new forms of work organizations (NFWO)* (Cagliano et al., 2014) and *collaborative climate* (Sveiby and Simons, 2002) as two constituent factors of the OC. *NFWO* is "a set of interrelated and internally consistent work practices including a range of innovative human resource management and work design required to face the modern business context" (Cagliano et al., 2014). It constitutes the organizational structure, decentralization, and flexibility of work practices that aid in effectively performing tasks in integrated organizations. The *collaborative climate* of a firm depicts the information exchange among levels of hierarchy, the extent of autonomy provided, and knowledge sharing through open communication (Sveiby and Simons, 2002).

The TC in this study is depicted by technologies used for the production process and those used for communication purposes (Paashuis and Boer, 1997). The production process technologies aid integration between design, product development, and manufacturing using CAD, CAM, CAPP[2], quality assurance tools, and techniques such as failure mode effect analysis and quality function deployment. Communication technologies such as the Internet, web conferencing, and social media aid interactions among employees and facilitate the bidirectional flow of information and knowledge.

The NFWO, collaborative climate, and production and communication technologies together facilitate product–process technology integration (Swink et al., 2007) that allow for accurate and timely dissemination of information among functional departments. The use of advanced manufacturing technologies (AMTs) such as CAD, CAM, and CAPP along with quality assurance tools and techniques such as failure mode effect analysis, quality function deployment, and rapid

[2] CAD: Computer-Aided Design, CAM: Computer-Aided Manufacturing, CAPP: Computer-Aided Production Planning.

prototyping support the concurrent production process through integration and interoperability of technologies (Swink and Nair, 2007). Design–manufacturing integration[3] requires rapid information dissemination and decision making enabled by coordination and utilization of joint wisdom. This is facilitated by organizational structure, work practices, communication infrastructure, decentralization, and knowledge exchange practices (March, 1991; Paashuis and Boer, 1997). In cases of bottlenecks, information dissemination and employees having autonomy will be able to resolve issues responsively (Das and Jayaram, 2003). Thus, in the context of DMTs, the employees will face a role transition from operators to problem solvers. This requires collaboration, coordination, and flexible work forms with lean structures that provide the necessary flexibility for employees to function responsively. From a CTE perspective, the combination of different organizational arrangements enables the functioning of integration technologies. Without the aforementioned work practices, integration and communication technologies could not be leveraged to their full potential. Hence, the organization structure, collaboration, and coordination practices have a considerable influence on the functioning of the technologies deployed. Therefore, we propose our first hypothesis:

H_1. *The organizational context positively impacts the technological context of the firm.*

3.2. Environmental context and technological context

The decision of replacing existing manufacturing technology and processes with advanced ones is dependent, to a large extent, on the type of environment faced by a business. This study uses technological dynamism (Dosi et al., 1994), competitive rivalry, the threat of product substitution, and bargaining power of customers as components of the external environment (Porter, 1991, 2008). These factors represent the industry and competitor aspects of the EC in the TOE framework that act as stimuli for technology adoption in firms (Dosi et al., 1994; Porter, 2001).

The volatile demand and ever-increasing competition pose a threat of product substitution, leading incumbents to adopt new technologies that aid the efficient production of new products (Porter, 2001). Firms tend to adopt computer-aided planning, design, and production systems which enhance efficiency and accuracy of the production process. The communication technologies facilitate real-time connectivity with customers and other functional departments, allowing seamless and error-free execution of the manufacturing process. Firms that are integrated are more responsive to changes in the external environment and towards customer demands (Hofmann and Rüsch, 2017; Battaïa et al., 2018). Hence, the more the competitive rivalry and threat of product substitution, the more the firms will focus on new technology adoption and bring changes to sustain profitability (Porter, 2008). Similarly, the rate of technological change within an industry also serves as a tipping point for change. Firms operating in a rapidly growing or declining market, or those functioning in industries with frequent changes and advances in technology also continuously need to upgrade themselves to retain their market share and remain competitive (Arvanitis and Hollenstein, 2001). Firms that are adept in technology use and vigilant towards market changes have an advantage of coping with these changes in a timely manner and sustain their competitiveness (Dosi et al., 1994). According to CTE, the success of technology implementation depends on its need in the firm as well as demand in the environment. The demand for customized products, shorter lead times, new variety, and responsiveness requires firms to be efficient in information dissemination and flexible and precise in their production processes. Hence, there is a need for advanced communication and production technologies (Mellor et al., 2014). Thus, we propose our second hypothesis:

H_2. *The environmental context positively impacts the technological context of the firm.*

3.3. Technological context and implementation of DMTs

The functioning of DMTs is made possible using information and communication technologies (ICTs) and AMTs (Brettel et al., 2014; Yu et al., 2015). A representative set of digital technologies include real-time tracking and data transmission by radio-frequency identification (RFID), three-dimensional (3D) printing, precision technologies, adaptive manufacturing systems, automated processes, and robotics as illustrated in the extant literature (Brettel et al., 2014; Strozzi et al., 2017; Dalenogare et al., 2018). RFID is used for tracking and tracing of products and manufacturing objects and collecting data in real-time for production (Strozzi et al., 2017). Digital manufacturing uses high precision technologies such as 3D printers, laser cutting, and water cutting (Dalenogare et al., 2018). Along with these manufacturing technologies, process automation and robotics are also an integral component of the digital manufacturing landscape. Process automation and the use of automated guided vehicles is not a new concept. However, the digital and reconfigurable nature of advanced technologies makes it easier for firms to switch to automation and use such vehicles at the shop floor level for efficient and seamless operations. Besides, demand volatility and increasing uncertainty call for reconfigurable manufacturing systems that have adjustable production capacity and changeable structures and aid flexibility and customization (Liao et al., 2017; Strozzi et al., 2017).

According to CTE theory, the existence and use of new technologies are made possible by the combination of existing operational processes and related technologies. The proper functioning of DMTs is enabled if the right supporting mechanisms are in place. These supporting mechanisms come from the already existing technologies used by the firm, which supports the proposition of CTE. The technological development of the firm is path-dependent and has a cumulative nature (Teece, 1996). The production process requires that DMTs are fed with digital models as inputs through software and hardware, which can then facilitate manufacturing. The manufacturing technologies thus require design and planning related AMTs to provide them with detailed information about the product (Yu et al., 2015). Simultaneously, open communication, collaboration, and decision making when used together with integration technologies allow the successful implementation of DMTs. Hence, we propose the third hypothesis as follows:

H_3. *The technological context of a firm positively impacts the implementation of digital manufacturing technologies in the firm.*

3.4. DMTs' implementation and operational performance

The relation between technology and different performance outcomes has been widely studied in the literature. Studies have found the impact of AMTs on innovation performance (Bourke and Roper, 2016), organizational performance (Raymond and St-Pierre, 2005), cost performance (Zelbst et al., 2010), and manufacturing performance (Beaumont and Schroder, 1997; Cheng et al., 2018). A few studies have been illustrated in Appendix A3. However, the relation between DMTs and performance is still under exploration and needs further investigation (Agrifoglio et al., 2017; Dalenogare et al., 2018).

Digitalization (including DMTs) enables consumer-centric outcomes that include high customization, quality, flexibility, transparency, resource and energy efficiency, and profitability (Brettel et al., 2014). We conceptualize the operational performance in terms of quality, design, flexibility, and delivery performance. The details of these measures are given in Appendix B and C. The high precision technologies,

[3] Design–manufacturing integration is defined as "the interaction and collaboration between design/engineering and manufacturing managers, who work together to arrive at mutually acceptable outcomes for their organization" (Thomé and Sousa, 2016).

robotics, and inbuilt adaptive ability of digital technologies allow variation in the level of productivity and facilitate in coping with varying demands of volume and variety (Strozzi et al., 2017). The real-time flow of information and the use of robotics can perform operations repeatedly without any error and delay, enhancing the conformance quality, delivery speed, and customization (Tracey et al., 1999; Esmaeilian et al., 2016). Moreover, the continuous flow of information, flexibility, and efficiency of digital technologies coupled with rapid prototyping technology enhance the innovation performance of the firm. The flexible work environment and bidirectional flow of information serve as triggers for innovative thoughts regarding the product, process, and continuous improvement of the production system (De Weck et al., 2014). Hence, DMTs and the smart factory environment and its beneficial outcomes provide firms with the ability to sustain the rapidly changing environment and consumer demands. Therefore, we hypothesize:

H_4. *The implementation of DMTs positively impacts the operational performance of the firm.*

3.5. Mediating effects

The CTE theory posits that new technologies are only successful when there exists a need for those technologies (Arthur, 2009). The rate of technological change, competitive rivalry, and the volatile market environment create a need for technologies that can cope with environmental changes and fulfil customer demands (Fatorachian and Kazemi, 2018). Owing to the constantly changing environment, firms are in a continuous cycle of upgrading their technical skills and competencies to remain competitive (Kiel et al., 2017). Firms that have a proactive outlook towards the external changes are more proficient in responding appropriately. In the realm of DMTs, firms leaping towards digital technologies need to have a suitable infrastructure in place that can support the optimum functioning of DMTs (Bokrantz et al., 2017; Bibby and Dehe, 2018). For such firms, with high proficiency and foresight, the advancements in production systems, and technology upgradation continuously evolve following the external forces (Porter, 2001). For DMTs, the requisite technological proficiency is provided by the design, production, and communication technologies (Ooi et al., 2018). These technologies serve as the basic infrastructure and allow the necessary level of integration and systems interoperability, which act as a foundation for the implementation of DMTs (Saldivar et al., 2015). This technical infrastructure is represented as the TC of the firm, which can either hinder or facilitate the implementation of new technologies (Depietro et al., 1990). Based on the foregoing, we hypothesize:

H_5. *The technological context mediates the relationship between environmental context and DMTs' implementation.*

In addition to the need for implementing DMTs, a specific OC also enables its implementation. The production and communication technologies aid internal integration, which can be leveraged by (re) designing organization structure, modifying coordination and collaboration practices such that they facilitate uninterrupted and smooth production processes (Swink and Nair, 2007). Moreover, the nature of integration technologies also requires employees to be multi-skilled and have the know-how of various functional departments so that there is no interruption in the manufacturing process. This, in turn, demands practices of job rotation, cross-functional and autonomous teams that may address issues without hampering the production process (Dubey et al., 2017). Hence, the OC impacts DMTs' implementation through the current technological state of the firm. Hence, our next hypothesis is as follows:

H_6. *The technological context mediates the relationship between organizational context and DMTs' implementation.*

The role of technologies in enhancing performance is well highlighted in the literature (Yang et al., 2011). It is theorized that existing technologies of design, production, and communication aid internal integration that set the stage for implementing and functioning of DMTs. Internal integration enables continuous information exchange and real-time connectivity among functional departments (Saldivar et al., 2015). The interoperability of these technologies with DMTs enables an uninterrupted manufacturing process, where real-time information facilitates process changes without hassle. The precision technologies along with the reconfigurable manufacturing technologies enable process flexibility in terms of volume or variety (Liao et al., 2017). Due to the continuous exchange of information and updates on consumer demands, a firm can innovate and introduce new products rapidly (Collins and Smith, 2006). Hence, TC supplements the use of DMTs and enhances operational performance. Based on this discussion, we propose the mediation hypothesis:

H_7. *The implementation of DMTs mediates the relationship between technological context and operational performance of the firm.*

Fig. 1 shows the hypothesized model, the different concepts being used in the study, and how these concepts are represented by CTE.

4. Research methodology

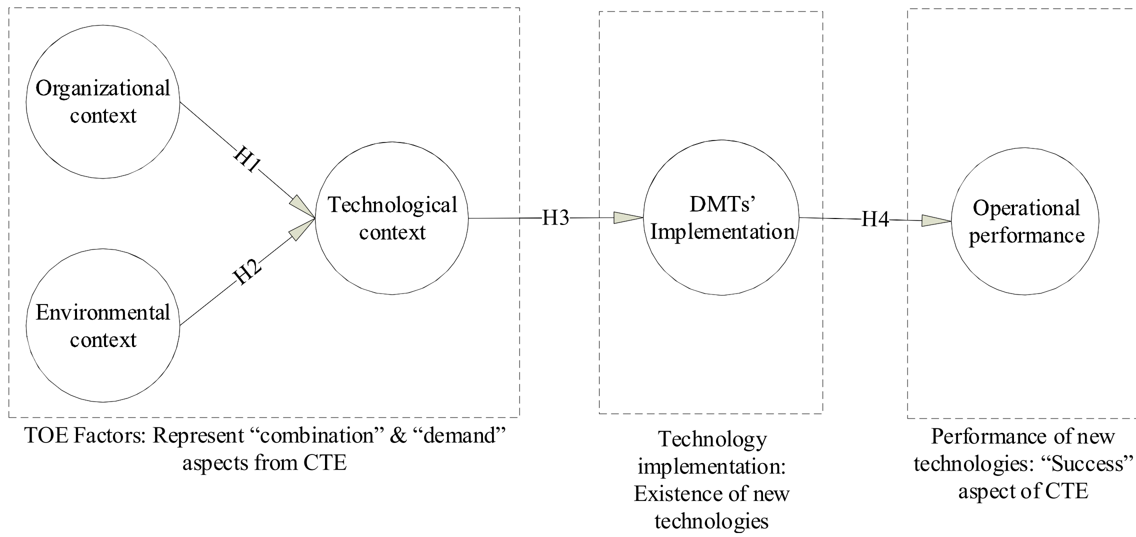
4.1. Data collection and sample

This research uses data from IMSS VI[4]—an outcome of the collaboration of a network of institutions and manufacturing companies, which was initiated by London Business School and the Chalmers University of Technology in 1992— for hypotheses testing. The survey investigates the manufacturing strategy, firm practices, and related factors at the plant level. Hence, the target respondents are plant managers, production managers, and operations managers. The survey is widely used in research and is implemented by international coordinators with the help of national coordinators. The International Manufacturing Strategy Survey (IMSS) questionnaire is designed to incorporate important issues relevant to manufacturing, the latest trends in the domain, and production and manufacturing processes (Caniato et al., 2013). Global datasets of this nature remain beneficial in exploring manufacturing practices for a considerable period of time as depicted in the literature (Cagliano and Spina, 2000; Hong et al., 2014). Further details about the International manufacturing strategy survey (IMSS) survey can be seen in many other research studies which have utilized it such as Voss and Blackmon (1998), Cagliano and Spina (2000), Frohlich and Dixon (2001), Frohlich and Westbrook (2001), Demeter (2003), and Yang et al. (2011) to name a few. Recent studies such as Boer and Boer (2019), Chaudhuri and Jayaram (2019), Hong et al. (2019), Wiengarten et al. (2019), Chaudhuri et al. (2018), Jajja et al. (2018), Haleem et al. (2017), and Cheng et al. (2016) have used IMSS VI data from 2014 to successfully research various topics.

Following a comprehensive process, the IMSS VI questionnaire was first developed in English and was translated into different languages using double and reverse translation procedures for use in various countries. The questionnaire was pre-tested before the official data collection procedure by managers. Based on the International Standard Industrial Classification (ISIC) code (ISIC 25–30) 7167 manufacturing firms were selected across different countries. A total of 2586 questionnaires were circulated in 22 countries from Europe, Asia, and America from June 2013 to June 2014. Data collected from the final sample of 931 firms was published in September 2014. The firms were selected from public and private databases and belonged to different manufacturing industries. The demographic details of the sample are provided in Table 1.

The methodology for data collection was common for all countries.

[4] http://www.manufacturingstrategy.net.



H_5: EC → TC → DMTs'

H_6: OC → TC → DMTs'

H_7: TC → DMTs' → OP

Fig. 1. Hypothesized model for implementation of DMTs.

The respondents in each country were supply chain managers, operations/production managers, or plant directors/managers, and were approached by the local researchers through email or phone. On agreement from the respondent side, the survey was sent through an email, fax, or postal service. If necessary, follow up from respondents was also conducted to enhance the response rate of the data (Zhao et al., 2008). Once the questionnaires were received, they were checked and handled on a case-by-case basis. The missing data for controls was addressed by contacting the plant again to increase the quality and completeness of data. The data was then stored in a database which was centrally coordinated by Politecnico Di Milano (Cheng et al., 2016).

Table 1
Demographics of sampled companies.

Number of employees	Number
0–1000	698
1001–2000	75
2001–3000	30
3001–4000	22
>4000	106
Industry	
Fabricated metal products, except machinery, and equipment (ISIC 25)	282
Computer, electronic, and optical products (ISIC 26)	123
Electrical equipment (ISIC 27)	153
Machinery and equipment not elsewhere classified (ISIC 28)	231
Motor vehicles, trailers, and semi-trailers (ISIC 29)	93
Other transport equipment (ISIC 30)	49
Region and Country	
Europe and North America	
Developed countries: Belgium (29), Canada (30), Denmark (39), Finland (34), Germany (15), Italy (48), Netherlands (49), Norway (26), Portugal (34), Slovenia (17), Spain (29), Sweden (32), Switzerland (30), USA (48)	
Developing countries: Hungary (57), Romania (40)	
Asia and South America	
Developed countries: Japan (82)	
Developing countries: Brazil (31), China (128), India (91), Malaysia (14), Taiwan (28)	

Moreover, the survey was designed and conducted in accordance with the recommendations of Podsakoff et al. (2003) to minimize common method bias and common method variance. Firstly, the predictor and criterion variables were placed in different sections of the questionnaire. Secondly, scale formats were different for the measurement of dependent and independent variables. Thirdly, the social desirability effect was reduced by maintaining the anonymity of respondents. Lastly, the survey used objective concepts, and explanation of items was included to reduce confusion.

In addition, the non-respondent and respondent biases were evaluated by the local research teams by accessing secondary data about the public profiles of the firm, which contained information related to the size, industry, ownership, and sales of the respondent firms. This information was then compared to the information in received responses; in cases where secondary information was not available, the biases were checked using relevant items in the questionnaire. However, the data did not demonstrate any notable signs of late-respondent or non-respondent bias (Cheng et al., 2016; Jajja et al., 2018).

4.2. Measures

All the constructs in this study were operationalized as reflective constructs (Diamantopoulos and Siguaw, 2006) except the EC, which was operationalized as a composite indicator. The EC was depicted by the intensity of competitive rivalry, the rate of technological change, the bargaining power of customers, and the threat of product substitution. Items for EC were adopted from Porter (2008) and Dosi et al. (1994) and provide a holistic picture of the competitive environment and the conditions of a marketplace that trigger the needs for technology adoption. The indicators of the construct are not the reflection of the EC; rather, these indicators cumulatively constitute, cause, and shape the EC (Commission, 2008; Diamantopoulos and Winklhofer, 2001; Diamantopoulos and Siguaw, 2006). Hence, it is appropriate to operationalize the EC as a formative construct as has been done in the literature

(Da Silveira, 2014). Further, the multidimensional nature of environmental factors has been presented in the literature (Grundy, 2006) and its use as a composite indicator has also been established by scholars (Diamantopoulos and Winklhofer, 2001; Hernández-Espallardo and Delgado-Ballester, 2009).

Multiple items using a five-point Likert scale were identified from the IMSS VI for the operationalization of the constructs. The constructs employed in this research, their dimensions, and supporting literature is summarized in Table 2. More details about items for each construct are presented in Appendix C.

The study uses firm size and industry as control variables to ensure that the contextual factors have been considered, as they may impact firms' behavior and performance (Cheng et al., 2016; Wiengarten et al., 2016). Although all firms (ISIC 25–30) belong to the manufacturing industry, yet the external business environment impacts the low-tech and high-tech industries in different ways (Demeter et al., 2011). Firm size has been operationalized as the logarithm of the number of employees in a business unit (Cheng et al., 2016). Industry was operationalized as a binary control variable with ISIC codes 26–27 coded as 1 (high-tech industries) and ISIC codes 25, 28, 29, and 30 represented as 0 (low-tech industries) (Wiengarten et al., 2016).

4.3. Measurement model testing

The measurement model of the constructs was tested using Confirmatory Factor Analysis (CFA) using AMOS version 22. The measurement model's fit indices ($\chi^2_{(d.f.=158)} = 343.005$, CMIN/d.f. = 2.171, GFI = 0.963, AGFI = 0.951, CFI = 0.972, RMSEA = 0.035, SRMR = 0.035) were satisfactory (Hu and Bentler, 1999). The values of Cronbach alpha, composite reliability, average variance extracted (AVE), and the factor loadings are shown in Appendix B.

The Cronbach alpha and composite reliability of each construct were above the value of 0.7, thus satisfying the reliability requirements of the constructs (Nunnally and Bernstein, 1967). Further, the factor loadings for each item were significant at $p < 0.001$ and had a value greater than 0.6, which also depicts the reliability of the constructs. The AVE values of all the constructs were greater than the threshold of 0.5 (Fornell and Larcker, 1981), thus satisfying the convergent validity. In addition, item loadings for all the constructs were significant at $p < 0.001$, thus providing additional evidence for the convergent validity of the constructs (Cheng et al., 2016). The unidimensionality of the constructs was established by estimating the Comparative Fit Index (CFI) of each construct (Falissard, 1999). For this study, the CFI of all constructs has a value greater than 0.90, thus satisfying the unidimensionality requirements. The squared inter-construct correlation (SIC) values were compared with the AVE values of the respective constructs in each pair to test discriminant validities. All SIC values were less than the AVE values of the constructs in the respective pair, except for the constructs of TC and DMTs' implementation. In this case, the AVE value of DMTs' implementation was less than the SIC value of TC and DMTs' implementation (Table 3). To further probe this issue, we conducted a chi-square difference test (Zaiţ and Bertea, 2011) between a constrained and unconstrained model. In the constrained model, the covariance between constructs was fixed to 1 and compared to an unconstrained model which was freely estimated. The chi-square difference between the two models was significant at $p < 0.05$, thus providing evidence for the satisfactory discriminant validity of DMTs' implementation (Fornell and Larcker, 1981).

4.4. Hypotheses testing

4.4.1. Direct hypotheses testing ($H_1 – H_4$)

The hypothesized model along with control variables was tested using structural equation modeling in AMOS version 22. Overall goodness of fit indices ($\chi^2_{(d.f.=222)} = 505.98$, CMIN/d.f. = 2.279, GFI = 0.953, AGFI = 0.942, CFI = 0.962, RMSEA = 0.037, SRMR = 0.052) were within the acceptable ranges (Hu and Bentler, 1999). The results show that all the hypothesized direct relationships are positive and significant at p-value < 0.001, which implies that the data supports H_1, H_2, H_3, and H_4 as shown in Fig. 2. The effect of industry and firm size was non-significant on the DMTs' implementation and operational performance.

4.4.2. Indirect hypotheses testing (H_5–H_7)

The mediation hypotheses were tested using bias-corrected bootstrapping method proposed by Preacher and Hayes (2008). The previous approach of Baron and Kenny (1986) has inferior statistical power as compared to the bootstrapping approach, which can test models with multiple mediators either in parallel or series, is more robust towards normality assumptions, and reduces Type I error (Rungtusanatham et al., 2014). We used the bootstrapping method with 5000 resamples to estimate the direct and indirect effects and their significance generated at a 95% confidence interval (Hayes, 2009). The mediation hypotheses of this study have been supported at $p < 0.05$, and the results show that the impact of EC and OC on DMTs' implementation is mediated by the TC of the firm (H_5, H_6). Further, the impact of TC on the operational performance is mediated by the DMTs' implementation (H_7) as shown in Table 4.

Moreover, given the direct effect of the EC on DMTs' implementation is non-significant, the TC has a full mediating effect in the relationship between EC and DMTs' implementation. However, because the direct effect of OC on DMTs' implementation is significantly positive, TC has only a partial mediating effect in the relationship between OC and DMTs' implementation. Similarly, the direct effect of TC on OP is

Table 2
Constructs, dimensions, and literature.

Construct	Dimensions	Literature
Organizational context	New forms of work organization and collaborative climate	Cagliano et al. (2011), Cagliano et al. (2014), Sveiby and Simons (2002)
Technological context	Production and design technologies and information and communication technology	Paashuis and Boer (1997), Cagliano et al. (2006)
Environmental context	Competitive rivalry, technological dynamism, threat of product substitution and bargaining power of customers	Porter (2008), Dosi et al. (1994)
Digital manufacturing technology implementation	3D printing and high precision technologies, smart/digital factory, reconfigurable manufacturing systems, automation, robotics and automated guided vehicles, and RFID	Vinodh et al. (2009), Hopkinson et al. (2006); Zuehlke (2010), Horbach et al. (2011), Wadhwa (2012); Zelbst et al. (2012)
Operational performance	Quality—product quality and conformance quality Delivery—delivery speed and delivery reliability Flexibility—mix flexibility and volume flexibility Design—new product introduction ability and product customization ability	Yang et al. (2010); Cua et al. (2001) Vachon and Klassen (2008); Cua et al. (2001) Vachon and Klassen (2008); Cua et al. (2001) Hallgren and Olhager (2009) Yang et al. (2010)

Table 3
Standard deviations and correlations of constructs.

Construct	SD	OC	EC	TC	DMTs'	OP	Firm Size
EC	0.595	0.175					
TC	0.959	0.503	0.204				
DMTs'	0.962	0.474	0.213	0.641			
OP	0.544	0.375	0.101	0.316	0.351		
Firm Size	1.720	0.189	0.110	0.106	0.044	0.071	
Industry	0.456	−0.015	−0.078	−0.062	−0.120	−0.005	0.026

SD: Standard Deviation, EC: Environmental context, TC: Technological context, OC: Organizational context, DMTs': Digital manufacturing technologies' implementation, OP: Operational performance.

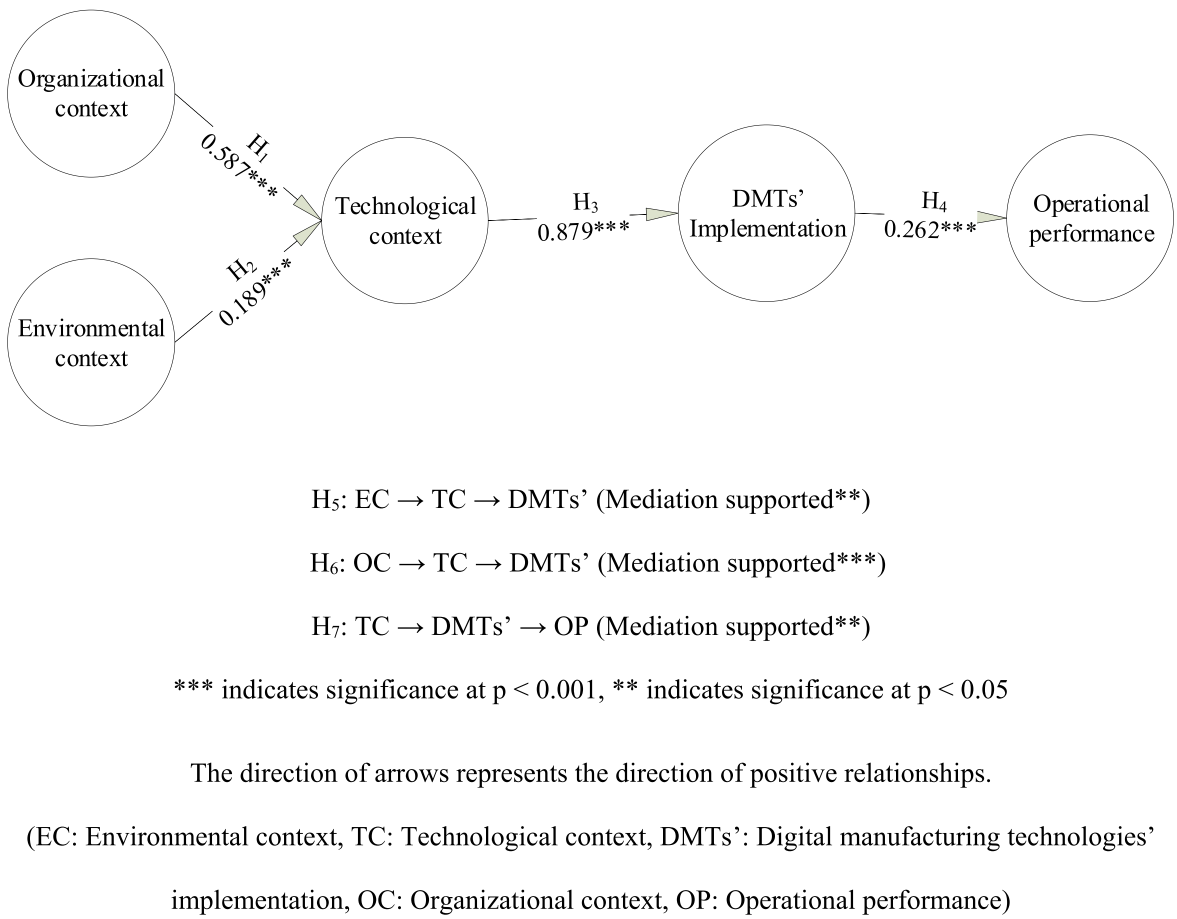


Fig. 2. Structural model results.

Table 4
Bootstrapping results for mediation hypotheses.

Hypothesis	IV	MV	DV	Effect of IV on MV	Effect of MV on DV	Direct effect	Indirect effect	SE of the indirect effect	95% CI for the indirect effect
H_5	EC	TC	DMTs'	0.143***	0.801***	0.058	0.115**	0.026	0.05–0.19
H_6	OC	TC	DMTs'	0.569***	0.801***	0.127**	0.456**	0.048	0.36–0.58
H_7	TC	DMTs'	OP	0.801***	0.143***	0.131**	0.114**	0.078	0.02–0.20

EC: Environmental context, TC: Technological context, OC: Organizational context, DMTs': Digital manufacturing technologies' implementation, OP: Operational performance, IV: Independent variable, MV: Mediating variable, DV: Dependent variable, SE: Standard error, CI: Confidence interval.
*** significance at $p < 0.001$.
** significance at $p < 0.05$.

significantly positive implying that DMTs' implementation has only a partial mediating effect in the relationship between TC and DMTs' implementation.

4.4.3. Additional analysis

The proposed model takes operational performance as a second-order construct; thus, we tested the appropriateness of this operationalization using established methods (Bollen and Long, 1992). First, the original model with second-order operationalization was compared to the one in which operational performance was replaced by four first-order performance measures, namely, flexibility performance, design performance, quality performance, and delivery performance. The modified model produced the goodness of fit indices ($\chi^2_{(d.f.=202)}$ = 1053.2, CMIN/d.f. = 5.214, GFI = 0.885, AGFI = 0.856, CFI = 0.886, RMSEA = 0.067, SRMR = 0.0853) that were inferior to the original model, providing support for the second-order operationalization (Cheng et al., 2016). Second, the factor loadings for the second-order construct are significant at $p < 0.001$, which depict the appropriateness of operationalizing operational performance as a second-order construct (Tippins and Sohi, 2003). Third, the target coefficient T-statistic was calculated by taking the ratio of chi-square value of the first-order CFA to the chi-square value of the second-order CFA (Cheng et al., 2016) using the formula: T-statistic = $\chi^2_{First\ Order}/\chi^2_{Second\ Order}$. The value of the T-statistic is 0.902, which is well above the threshold of 0.8, depicting that the second-order construct is better than the first-order construct (Marsh and Hocevar, 1985; Jajja et al., 2018).

In addition, to estimate the two double-mediating effects, we followed the user-defined estimands approach in AMOS (Arbuckle, 2010; Kosiba et al., 2018). The results of the double-mediation analysis are presented in Table 5, which shows that the OC and EC impact performance through TC and DMTs implementation. The direct path from the OC to the operational performance is positive and significant, whereas from the EC to the operational performance is non-significant.

Finally, we tested the robustness of the hypothesized model using contextual analysis as done by Yang et al. (2011). The analysis was conducted to examine regional and national differences that are likely to exist in large and diverse samples (Frohlich and Dixon, 2001). The sample was segregated into three different groups, namely, small firms (size < 250 employees) versus medium/large firms (size > 250 employees), developed countries versus developing countries, and European firms versus Asian/South American firms. All hypotheses remained significant for all the regions and different firm sizes except for H_2, as illustrated in Table 6. For small firms, Asian and South American firms and the firms in developing countries, the impact of EC on TC was non-significant.

5. Discussion

5.1. Association between TOE and DMTs' implementation

Manufacturing firms are struggling to remain competitive amidst changing digital technology trends (Yin et al., 2018). The lack of knowledge of the factors enabling digitalization poses challenges to the practitioners. This study posits that the successful implementation of DMTs is driven by external environmental factors enabled by appropriate organizational structures, internal work practices, and the technological state of the firm. This study used the TOE framework, which provides the flexibility to include the relevant factors important for particular technology implementation. This study determines the drivers and enablers of DMTs using the TOE framework (Liao et al., 2017; Strozzi et al., 2017; Zangiacomi et al., 2017), and thus provides foundational work in this domain.

The CTE theory has been used to describe the underlying mechanism indicating how the strategic contexts impact technology implementation in a firm. Studies show that firms follow an incremental model for technology implementation where the existing technological state serves as a stepping stone for the new ones (Arthur, 2009; Frank et al., 2019a; Small and Yasin, 1997; Teece, 1996). This phenomenon has been well highlighted in the seminal article of Teece (1996) where the author describes path dependency, cumulative nature, and interrelatedness as the fundamental characteristics of the technological development of a firm. The mediating relationships of this study borrow support from the literature and posit that the new technologies have a path dependency on the previous technologies being used (H_3). Moreover, the cumulative effect of technologies has a positive impact on the performance of the firm (H_7). The findings of this study support the mentioned mediating hypotheses and are aligned with the conceptual propositions of Frank et al. (2019a) who propose technology implementation phenomenon to be sequential where front-end technologies (smart supply chain, smart working, smart manufacturing, and smart product) are dependent on the existence of base technologies (Internet of Things, cloud, big data, and analytics). The base technologies provide the infrastructure for the front-end technologies and support their appropriate functioning. The findings of our study reinforce this view and show that the integration and communication technologies support the functioning of the DMTs (H_3).

The extant literature on the TOE framework has generally used the enabling contexts as simultaneous enablers and posits that they impact the technology adoption processes of a firm (Appendix A2). Our study moves away from this traditional connotation and proposes that the TC of a firm mediates the relation between OC and EC and new technology implementation. This proposition is in line with the incremental model of technology adoption in a firm as presented by Frank et al. (2019a)a, who posit the dependence of front-end technologies on base technologies, which form the basic infrastructure for connectivity. The same phenomenon has been documented in the seminal article of Teece (1996), which describes that new technology adoption in organizations has a cumulative nature and is path-dependent on previous technologies. The study of Tushman and Murmann (1998) about dominant designs and technology cycles also supports the aforementioned notion and states how new technology systems evolve from existing technologies and have important linking mechanisms that are essential for the overall performance.

The digital technologies used in the production process require little labor and high information tackling. Hence, functional departments need to be integrated for the timeliness of the information (Belvedere and Grando, 2017). The importance of autonomous teams, job rotation, and work flexibility increase in such an automated environment to enhance responsiveness (Hofmann and Rüsch, 2017). Timely decision making is enabled when the organizational hierarchy is flatter, authority is delegated, information flows are bidirectional, workers are knowledgeable, and flexibility in work processes is allowed (Bibby and Dehe, 2018). These workplace characteristics are required to cope with the changes in the external environment (Tortorella and Fettermann, 2018). Therefore, it becomes essential to understand the external environment that triggers the change (Porter, 1991, 2008). The advent of the digital era has raised expectations and awareness of customers, who have become highly demanding in terms of the introduction of customized and innovative products at a rapid pace. This puts pressure on firms to

Table 5
Double-mediation results.

Mediation Path	Direct effect	Indirect effect	SE of the indirect effect	95% CI for the indirect effect
OC→TC→DMTs'→OP	0.177**	0.057**	0.021	0.018–0.105
EC→TC→DMTs'→OP	−0.001	0.015**	0.007	0.005–0.035

OC: Organizational context, TC: Technological context, DMTs': Digital manufacturing technologies' implementation, OP: Operational performance, EC: Environmental context.
** = significance at $p < 0.05$.

Table 6
Contextual analysis of the hypothesized model.

Hypotheses	Effects	Aggregated sample[a]	Firm size		Regions			
			Small (n = 410)	Medium/Large (n = 521)	Europe and North America (n = 557)	Asia and South America (n = 374)	Developed countries (n = 542)	Developing countries (n = 389)
H_1	OC→TC	0.62***	0.61***	0.61***	0.58***	0.68***	0.55***	0.65***
H_2	EC→TC	0.13***	0.08	0.14***	0.17***	0.09	0.19***	0.04
H_3	TC→DMTs'	0.82***	0.78***	0.83***	0.82***	0.81***	0.80***	0.80***
H_4	DMTs'→OP	0.42***	0.35***	0.46***	0.35***	0.47***	0.31***	0.42***
H_5	OC→TC→DMTs'	0.45***	0.42***	0.46***	0.37***	0.55***	0.38***	0.47***
H_6	EC→TC→DMTs'	0.12***	0.07	0.13***	0.14***	0.07	0.16***	0.02
H_7	TC→DMTs'→OP	0.11***	0.09	0.13	0.17***	0.06	0.17***	0.06

OC: Organizational context, TC: Technological context, EC: Environmental context, DMTs' = Digital manufacturing technologies' implementation, OP: Operational performance.
*** significance at $p < 0.01$.
[a] Aggregated model was tested without control variables. For H_5–H_7, the indirect effects have been mentioned.

do more to avoid product substitution. Similarly, ICTs and DMTs have made it much easier for new businesses to enter the market and pose competition to incumbents (Hofmann and Rüsch, 2017). Technology (and more so, digital technology) upgradation and customer expectations have currently formed a reinforcing loop (Gunasekaran et al., 2018). Hence, to remain profitable and competitive, firms need to comply with market changes and take measures for their upgradation (Brettel et al., 2014).

However, an important factor that may limit this technology upgradation, and specifically DMTs' implementation is the current technological proficiency of the firm (Frank et al., 2019a; Mellor et al., 2014). Firms that are proficient in the use of technologies for administration, production, design, and manufacturing will face little difficulty in bringing new changes (Brandyberry et al., 1999; Small and Yasin, 1997). On the contrary, firms that are not technology savvy are expected to face significant hurdles in making the transition to digital manufacturing as they lack the required physical infrastructure (Mellor et al., 2014). Firms equipped with conventional technologies have already gone through some level of organizational changes. Hence, further technology adoption demands fewer changes from such firms. This connotation is aligned with the CTE perspective, which posits that the use of new technologies will only be successful if the existing technologies and processes are functioning seamlessly and align with the requirements of the new technology. The mediation hypotheses of this study reinforce this view and are aligned with the conceptual explanation of the TOE framework, which proposes that the current technologies being used by a firm set a limit on the further adoption of new technologies (Depietro et al., 1990). Hence, the TC of the firm acts as a mediator between the EC and OC link and DMTs' implementation.

The aforementioned connotations are supported by the findings from contextual analysis as well. The findings reveal that all the hypotheses remain significant for different demographic regions and countries except for the direct and indirect impact of EC on TC, DMTs' implementation, and manufacturing performance, respectively (H_2, H_6, and H_7). This relationship is non-significant for small firms (size < 250), for firms in Asia and South America, and developing countries. This is an interesting finding as a significant volume of the extant literature documents that the environment in which a firm operates, impacts the strategy and decision making of the firm (Amoako-Gyampah and Acquaah, 2008; Badri et al., 2000; Ilin et al., 2017; Kim and Lim, 1988). For developing economies, just as in developed economies, the consumer demand is highly volatile, and irrespective of the multiple challenges, firms still need to upgrade their tools and practices to remain competitive (Fatorachian and Kazemi, 2018). Moreover, continuous advancements and innovations in information technology increase the competitiveness of both developed and developing countries at a rapid pace (Sabi et al., 2018). Hence, owing to the turbulent and chaotic environment, firms have to make smart technology choices that provide them with a competitive advantage for survival (Huo et al., 2014). However, it is interesting to see that the findings of our study also gain support from the existing literature. Ehie and Muogboh (2016) conducted a study on the formulation of manufacturing strategy in developing countries; the findings reveal a non-significant effect between the competitiveness of the environment and manufacturing strategy of the firm. The study by Ilin et al. (2017) also supports our findings and show that the pressures from the industry do not impact the adoption of new technologies in firms that function in developing countries.

The environment in developing countries is complex and chaotic due to multiple factors, namely, lack of research and development and innovation, weak government regulations, low efficiency at the state level, and the dearth of competent suppliers, to name a few (Peña-Vinces et al., 2012). These factors do not provide a sufficient supportive infrastructure that is required for the diffusion of technologies in organizations (Ehie and Muogboh, 2016). In such environments, the competency of adopting and utilizing advanced manufacturing tools and practices is inhibited by the abovementioned challenges (Sabi et al., 2018), and hence, firms are not proactive at adopting new technologies. Another reason can be the managers' skepticism towards the adoption of new technologies in the existing systems. They might not perceive these technologies as necessary even when experiencing industry pressures to upgrade (Ilin et al., 2017). The lack of technical capability and knowledge and the absence of upgraded infrastructure in firms can be another plausible explanation of why the relationship is non-significant for developing countries (Mangla et al., 2018). Firms in these countries do not realize the potential of modern information systems and infrastructure, and thus, are not inclined towards their usage. The non-existence of training, knowledge, and awareness all contribute to the non-adoption of advanced systems in these countries. In the realm of DMTs, Tortorella et al. (2019) also provide an explanation for the low adoption of DMTs for firms in developing countries. They posit that firms in these countries have ill-structured processes and the adoption of process technologies does not integrate to produce the required value. Hence, firms are not motivated to implement new technologies.

Similarly, for Asian and South American countries in our data sample, the aforementioned explanations are valid, as the countries in these regions are all developing economies except Japan. Hence, the aforementioned possible explanations remain valid in comprehending the non-significance of the relationship between EC and TC.

For small firms, the pressure from industry is not severe, and hence, the external environment does not play a major role in technology adoption and decision making of the firm (Kuan and Chau, 2001). Small firms function in resource-constrained environments and lack financial strength (Lindell and Karagozoglu, 1997). Financial investments and the lack of awareness around the benefits of new technologies also act as a barrier in technology upgradation for these firms (Ilin et al., 2017). Small firms have more fluid processes and the operations of the firms have limited routine activities and are also constrained by their resources. Thus, the acquisition of technology and making relevant changes in the organization is a big leap that is seldom taken (Beck and Demirguc-Kunt, 2006). The findings of this study support the aforementioned understanding and imply that the effect of the external environment is dominant in developed economies and for large firms. These firms are at an advantage of having the required resources to create knowledge, implement technologies, and utilize them effectively (Zhu et al., 2006).

5.2. Association between DMTs' implementation and performance

The promising results of DMTs in terms of operational performance have been empirically endorsed in this study. The positive performance implications of digital technologies in the realm of manufacturing have been repeatedly mentioned in the extant literature (Buer et al., 2018; Belvedere and Grando, 2017; Dalenogare et al., 2018; Gunasekaran et al., 2018). The findings of our study reinforce these conceptual propositions and depict the different performance implications which can be enhanced using DMTs such as flexibility, delivery, design, and quality performance. The digital and reconfigurable nature of these technologies facilitate information exchange and enhance the flexibility of the production system. The reduction of bullwhip effect due to timely information exchange enhances the delivery speed and reliability, which adds to the responsiveness of the firm (de Sousa Jabbour et al., 2018). The information exchange also aids in creating an innovative environment that is facilitated by the flexibility of the production system, organic structure of the organization, and information sharing in the firm (Dalenogare et al., 2018). The inbuilt flexibility of these technologies aid volume and mix flexibility, and allow for timely and accurate planning, manufacturing, and delivery. The real-time information exchange aids in maintaining connectivity with partnering firms and customers, which provides firms with the advantage of being more responsive (Bokrantz et al., 2017).

An interesting finding revealed by the study is that the impact of DMTs on performance is higher for developing countries as compared to developed countries (refer to Table 6). A possible explanation for this increase in performance is that the manufacturing firms in developed countries are proficient in the use of technologies, and hence, the use of DMTs results in incremental performance improvement. As against this, in developing countries, the manufacturing firms are less technologically proficient and the adoption of DMTs enhances the performance outcomes to a greater extent. This rationale is also supported by the mediating relationship (H_7) of the study, which shows that the TC impacts the operational performance of the firm through DMTs. For developed countries, this mediating relationship is supported whereas it is non-significant for the firms in developing countries. The technological proficiency of firms, as represented by the TC in this study, is not much advanced in the case of developing countries (Hadjimanolis, 1999), and therefore, there is no considerable effect of the TC on performance. While developed countries are the hub of innovation and new knowledge generation and are at a much advanced level in their use of technology (Bell and Pavitt, 1997), therefore, the high technological proficiency has a noticeable impact on the performance of the firm.

5.3. Association between TOE, DMTs' implementation and performance

As shown in the study, the double-mediation paths, from OC to operational performance and EC to operational performance are significant and provide useful insights. The direct effect of OC on operational performance is significant and depicts that changes in the organization structure, autonomy, workforce flexibility, and collaborative practices have a positive impact on performance measures of the firm. These changes facilitate uninterrupted functioning of day-to-day tasks by enabling information exchange, quick decision making, and prompt problem-solving (Cagliano et al., 2014). The indirect effect of OC on operational performance shows that the technological proficiency of the firm and the implementation of new technologies complements the organizational changes and has a positive impact on firm performance (Brandyberry et al., 1999). The EC has a non-significant direct effect and a significant indirect effect on operational performance. The non-significant direct effect can be explained by the fact that the changes in the external environment would not affect a firm's performance unless the firm takes some measures to cope with these changes. Although non-significant, the negative sign of the EC is self-explanatory as the changes in the competitive pressures, technological innovations, and rapid customer changes will have a negative influence on the incumbents. The significance of the indirect effect depicts that when firms take measures to cope with external changes, the performance of the firm improves through technical proficiency (Small and Yasin, 1997) and DMTs' implementation.

5.4. Theoretical implications

This study has implications not only for operations and supply chain management literature but also for technology adoption and digitalization literature. Digitalization literature has emphasized the need for technology implementation guidelines (Strozzi et al., 2017; Frank et al., 2019a). Digital technology implementation guidelines may take various forms, such as outlining (a) specific factors that enable or inhibit successful digital technology implementation, whether they are DMTs or general digital technologies suitable for any organizational division, (b) step-by-step guidelines on how firms can transform themselves into a digitalized state, and (c) successful strategies or approaches for implementing digital technologies. With regard to these questions, this study relates to point (a) and may serve as a starting point for identifying specific enablers that result in successful DMTs' implementations. Secondly, this study partially addresses point (b) and informs the unique interplay and sequence of the broader TOE contexts that foster DMTs' implementation, which is also supported by the CTE theory that encapsulates the holistic perspective on technology implementation. However, the prescriptive stepwise and detailed guidelines about the implementation of various factors can be investigated in future studies.

The domain of digitalization is still in its early stages and needs to be developed through conceptual and empirical studies. This study is an initial step in addressing this gap and provides empirical constructs for concepts relevant to digitalization, which can be beneficial for future studies. The study presents the TOE contexts in a specific order rather than simultaneous enablers, which has majorly been the case for studies using the TOE framework (refer to Appendix A2). We posit that the OC and EC will impact technology implementation, however, the TC will act as a mediating factor. The significance of the proposed sequence is aligned with the connotations of technology adoption where a sequential progressive pattern is the norm (Teece, 1996; Frank et al., 2019a). This proposed relationship in which the TC mediates the relationships between the environmental and organizational perspectives and the DMTs' implementation provides an alternative (with respect to Teece, 1996; Frank et al., 2019a) understanding of the interplay of the TOE contexts and can open new directions for exploration. It is also established that successful DMTs' implementation is a result of the push (environmental) and pull (technological and organizational) factors (Dalenogare et al., 2018). Simultaneously, the successful implementation of DMTs requires a holistic socio-technical system improvement-based approach rather than the insulated technological or social system-based approaches (Fatorachian and Kazemi, 2018; Yin et al., 2018).

In this study, the specific interplay of the TOE factors and their impact on DMTs' implementation have used CTE as a theoretical lens to explain the implementation process. The use of CTE in literature has been limited, and even if used, it has not been explored to the full potential (Holmström and Partanen, 2014; Yoo et al., 2012; Youn et al., 2015). CTE has three important dimensions—combination, demand,

and success (Arthur, 2009). Studies have usually focused on the "combination" dimension while ignoring the remaining two (Holmström and Partanen, 2014; Yoo et al., 2012; Youn et al., 2015). This study utilizes all three dimensions, and thus, not only extends the use of the theory but also provides a richer and comprehensive explanation of the technology implementation process. Future studies can further validate this understanding, and in doing so, can explore further processes (and/or sub-processes) that are at play in the technological evolution of firms.

In addition to the use of CTE and TOE factors to explain technology implementation, we empirically endorse and determine the significance of OC, EC and TC in DMTs' implementation. The identification of antecedents for digital manufacturing has been much called for in the extant literature (Breunig et al., 2016; Strozzi et al., 2017). This study aims to address this call for research and contributes its share to the relevant body of knowledge (Castelo-Branco et al., 2019; Lee et al., 2018; Li, 2018b; Xu et al., 2018).

This study has also attempted to address the concern regarding the performance implications of DMTs. The uncertainty regarding DMTs' performance has also been a challenge in the implementation process (Dalenogare et al., 2018; Moeuf et al., 2018). This study empirically endorses the role DMTs play in improving the flexibility, design, quality, and delivery performance, thus increasing confidence in the use of DMTs. In addition, this study also extends the use of the TOE framework in establishing the relation between enabling contexts and performance of the firm, which has been largely missing in previous studies (Dalenogare et al., 2018; Frank et al., 2019a; Strozzi et al., 2017). This extension contributes to the understanding of requisite organizational forms and technological states that can enhance the performance outcomes in the presence or absence of other contingencies.

5.5. Managerial implications

This research has several implications for managers. Firstly, it guides in assessing organizational readiness for digital technology adoption and provides an overall idea of the organizational and technological state that is required for DMTs' implementation. Managers need to focus their efforts in routinizing flexible work practices, enhance coordination and collaboration, establish a bidirectional flow of information, provide autonomy to employees, and take initiatives for continuous improvement. Such an environment is more conducive to the new use of technology and enhances the acceptability and the use of technology. Secondly, the study also establishes design–manufacturing integration as an important element for the use of DMTs. This is enabled by the combination of NFWO and collaborative climate of the firm together with computer-aided technologies which allow different departments to coherently work on design, production, and quality of the product (Hofmann and Rüsch, 2017; Thomé and Sousa, 2016; Swink and Nair, 2007). On the one hand, cross-functional teams, job rotation, and collaboration among functional departments enhance the coordination, whereas on the other hand, technologies such as CAD, CAM, and CAPP and ICTs facilitate a seamless design and manufacturing process (Wang and Zhang, 2002). These work practices and technologies cumulatively provide the integration necessary for the functioning of DMTs (Bokrantz et al., 2017). Thirdly, managers of today are under pressure to concurrently perform and produce required results on conflicting objectives such as quality, delivery, cost-effectiveness, and customization (Fatorachian and Kazemi, 2018). This study outlines different digital technologies that can produce favorable outcomes in these managerial pursuits. The use of high precision technologies such as 3D printers enhances the design quality of the products. Reconfigurable and scalable manufacturing systems enhance the flexibility of the production system, the development towards smart factory adoption enhances the exchange of real-time information, reducing the bullwhip effect (Brettel et al., 2014; Zuehlke, 2010). The real-time exchange of information has an impact on the accuracy of the production system, quality and conformance of the product, flexibility to incorporate changes in volume and variety, and timely delivery of the product. These aspects guide managers to decide which technologies shall be used to attain the required performance outcomes. Fourthly, the study identifies the different possible external pressures such as competitive rivalry, the threat of product substitution, changing customer demands, and rate of technological change, which may be managed by DMTs' implementation. These DMTs enhance the operational performance of the manufacturing firm and aid it in surviving the competitive environment.

Lastly, as shown in the additional analysis (section 4.4.3), the hypothesized relationships hold for both small and large firms, which shows that DMTs' implementation is not restricted only to larger firms and that managers of small firms can benefit from the findings and embark their journey to digital manufacturing. Similarly, the findings of this study can guide managers of manufacturing firms in developed as well as developing countries. The driving forces, enabling factors, and performance outcomes of DMTs can inform managers on different aspects of technology implementation and help maneuver their move towards digital manufacturing, thereby benefiting from the findings of this study.

6. Limitations and future research directions

This study has its share of limitations as well. Firstly, it is based on cross-sectional data whereas longitudinal studies are considered to be more suited for topics such as technology implementation, as it happens over a period of time. Secondly, an important constraint of this study is that DMTs is operationalized only in terms of digital technologies, namely, 3D printers, high precision technologies, reconfigurable manufacturing systems, digital/smart factory, and RFIDs. There are other technologies such as the Internet of Things, cloud, analytics, and artificial intelligence which should also be part of the digital technology representation in future research. Thirdly, other than the TOE contexts, there are several other factors related to financing and human resources, which can also act as enablers or inhibitors for technology implementation. Those factors are not considered in this study. Similarly, the performance implications of the implementation of DMTs could be partly impacted by financial measures, which can be investigated in future studies. Fourth, the relationship between the EC and TC in developing economies requires further investigation to identify if other extraneous or contingent factors are at play that hinder the technological proficiency of firms and upgradation of their basic technology infrastructure. Lastly, although studies based on global datasets have more generalizability, there might be issues associated with heterogeneity in the sample. This study has attempted to address the issue testing for heterogeneity issues using established methods such as contextual analysis, where the hypothesized model has been tested for small versus large firms, firms in developed versus developing countries, and firms in Europe and North American countries versus Asian and South American countries. Though no notable differences between various subsamples were found in this study, caution should be exercised in generalizing the findings of this research. Moreover, owing to technological advancements, future studies can use recent datasets for studies pertaining to barriers and enablers of digital technology to provide an updated view of the practices relevant to digital technology implementation. This study investigates the phenomenon of the implementation of DMTs as a generalizable unison; however, it may be influenced by the business models adopted by firms. Future studies can develop this understanding, and this study can serve as a starting point in this respect. Besides, this study uses TC as a contingent factor in DMTs' implementation. Future studies can identify other contingencies that may impact the technological development of digital manufacturing.

Appendix A1. Representative studies depicting research on digital manufacturing

Topic	Authors	Journal	Method	Scope and Findings
Exploratory studies on Industry 4.0, its components and research status	Liao et al. (2017)	IJPR	Literature Review	• Academic progress related to industry 4.0 in terms of hardware, software and applied standards, the focus of current research and priorities for future research.
	Strozzi et al. (2017)	IJPR	Literature Review	• Systematic literature review on smart factory highlighting research domains namely RFID, smart manufacturing landscape and implementation of the smart factory.
	Oztemel and Gursev (2018)	JIM	Literature Review	• Reviews industry 4.0 and its major technologies, design principles, advantages and disadvantages of digital transformation, and avenues for future research.
	Reischauer (2018)	TFSC	Review Paper	• Illustrates Industry 4.0 as a policy-driven innovation discourse in manufacturing which includes the business community, academics and politics.
	Sung (2018)	TFSC	Review Paper	• Provides policy implications for Korean manufacturing firms for the transition towards industry 4.0.
	Chiarello et al. (2018)	CII	Review Paper	• Reviews different technologies and terms used for industry 4.0 and establishes linkages between them for future research and the advancement of the domain.
Smart manufacturing	Kusiak (2018)	IJPR	Review Paper	• Identifies six pillars of smart manufacturing as technology and processes, data, materials, predictive engineering, sustainability and resource sharing and networking.
	Yin et al. (2018)	IJPR	Review Paper	• Reviews the evolution of production systems from industry 1.0 through industry 4.0 from the product supply and customer demand point of view.
	Dolgui et al. (2019)	IJPR	Review Paper	• Groups different analytical models for the optimal control of scheduling for production, supply chain and industry 4.0 systems.
Industry 4.0 and Lean Production	Tortorella and Fettermann (2018)	IJPR	Survey	• Firms in an emerging economy inclined towards improving their lean practices are more prepared and willing to adopt industry 4.0 technologies.
	Buer et al. (2018)	IJPR	Literature Review	• Provides insights on the link between lean manufacturing and industry 4.0 and provides future research directions.
Industry 4.0 and sustainability	de Sousa Jabbour et al. (2018)	TFSC	Conceptual paper	• Proposes an integrative framework on simultaneous adoption of industry 4.0 technologies and environmentally sustainable manufacturing.
	Holmström et al. (2017)	JCP	Conceptual paper	• Shows how the use of Direct Digital Manufacturing (DDM) changes operational practices and capabilities of a firm which further enhance the sustainability outcomes.
Implementation of industry 4.0	Bokrantz et al. (2017)	IJPE	Empirical Delphi based	• Identifies big data analytics data management, maintenance planning, interoperability and prediction of environmental impact as important themes for maintenance.
	Kamble et al. (2018)	CII	Analytical	• Illustrates barriers to industry 4.0 in the Indian manufacturing sector such as employment disruptions, investments, organizational changes, lack of technology-related knowledge and compliance issues.
	Xu et al. (2018)	IJPR	Review Paper	• Informs the identification and development of capabilities according to the sophisticated technologies of industry 4.0.
	Bibby and Dehe (2018)	PPC	Interviews	• Proposes an Industry 4.0 assessment framework for the defense manufacturing sector using three dimensions of: "factory of the future", "people and culture" and "strategy".
	Frank et al., 2019a	IJPE	Survey	• Proposes systemic adoption patterns of industry 4.0 technologies by dividing them into base technologies and front-end technologies.
	Gattullo et al. (2019)	RCIM	Case Study	• Proposes a method for the implementation of augmented reality documentation in industry 4.0 environment using text optimization and 2D graphic symbols.
	Lee et al. (2018)	ML	Review paper	• Strategizes the implementation and the use of artificial intelligence by providing the characteristics of the required ecosystem.
	Castelo-Branco et al. (2019)	CII	Review Paper	• Identifies digital infrastructure and analytics capability as the two factors which characterize industry 4.0 readiness for manufacturing firms in European countries.
	Horváth and Szabó (2019)	TFSC	Empirical Qualitative	• Identifies real-time performance measurement and increased control as driving factors of industry 4.0 and organizational resistance as the main barrier for the adoption of industry 4.0.
	Li (2018b)	TFSC	Review Paper	• Comparison of China's "Made in China 2025" plan and Germany's "Industry 4.0". Critical factors for the implementation of China's strategic plan in the digital era are identified.
Industry 4.0 and Servitization	Rymaszewska et al. (2017)	IJPE	Case study	• Explores how servitization can benefit from use of data from the Internet of Things through different means.
	Cenamor et al. (2017)	IJPE	Case study	• This study finds that platform approach benefits service offerings by leveraging value from the information; increase operational efficiency, flexibility and customized offerings.
	Frank et al., 2019b	TFSC	Conceptual	• Conceptual framework at the intersection of industry 4.0 and servitization proposed. Develop nine configurations of industry 4.0 related services which focus on smoothing, adapting or substituting services.
Industry 4.0 and Logistics Management	Holmström and Partanen (2014)	SCM: IJ	Conceptual	• Explores combinations of digital manufacturing, logistics and equipment use and their implications for logistic service providers and supply chain management practice.
	Hofmann and Rüsch (2017)	CII	Conceptual	• Explores the opportunities of industry 4.0 technologies in the realm of logistics management specifically for cross-company Kanban and Just in time/just in sequence systems.
Performance of Industry 4.0 technologies	Moeuf et al. (2018)	IJPR	Review Paper	• Illustrates that SMEs do not invest in all resources of industry 4.0 rather adopt cloud computing and the Internet of Things which are used only for process monitoring.
	Szalavetz (2019)	TFSC	Interview-based	• Investigates the impact of AMT on manufacturing subsidiary capabilities.

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Topic	Authors	Journal	Method	Scope and Findings
	Dalenogare et al. (2018)	IJPE	Survey	• Empirically measures the impact industry 4.0 technologies have on different performance indicators in the Brazilian manufacturing context.
	Agrifoglio et al. (2017)	PPC	Case Study	• Explores the impact of IoTs and computational technologies on operations management through customer value co-creation in the context of the Maritime industry.

Appendix A2. Use of TOE framework for different technologies

Author & Year	Journal	TOE Contexts	Focus of Study	Findings ("→" = lead(s) to)
Chan and Chong (2013)	IJPR	Simultaneous	Determinants of Mobile Supply Chain Management (m-SCM) diffusion in Malaysian manufacturing firms	• Technological and organizational Factors → diffusion of m-SCM • Environmental Factors partially → diffusion of m-SCM
Aboelmaged (2014)	IJIM	Simultaneous	Determinants of e-maintenance readiness in manufacturing firms	• Technology Infrastructure, competence and firm size → e-maintenance readiness • Expected e-maintenance benefits and firms' maintenance priority partially → e-maintenance readiness • Expected e-maintenance challenges negatively → e-maintenance readiness • Competitive pressure does not → e-maintenance readiness
Lin and Lin (2008)	Technovation	Simultaneous	Determinants of e-business diffusion	• IS infrastructure, IS Expertise, expected benefits and competitive pressure → e-business adoption • Organizational Compatibility and trading partner readiness does not → e-business adoption
Wang et al. (2010)	TFSC	Simultaneous	Determinants affecting RFID adoption in manufacturing firms in Taiwan	• Technological complexity negatively → RFID adoption • Technological compatibility, firm size and competitive pressure → RFID adoption • Relative advantage, technology competence, top management support does not → RFID adoption
Ilin et al. (2017)	TFSC	Simultaneous	Determinants of e-business adoption in ERP enabled and non-ERP enabled firms in developing countries	• Lack of technological factors negatively and partially → e-business adoption in ERP enabled and ERP non-enabled firms • Organizational factors partially → e-business adoption in ERP enabled firms • Organizational factors negatively and partially → e-business adoption in ERP non-enabled firms • Environmental factors → e-business adoption in ERP enabled and ERP non-enabled firms
Ramanathan et al. (2017)	PPC	Simultaneous	Antecedents of business analytics adoption in retail firms	• IT human assets, technology assets, relationship assets, top-level support, complementary investments, business type, business Pressure and market environment → Adoption of Business Analytics
Wu and Chen (2014)	TFSC	Simultaneous and TOE as moderator	Examine the relationship between IS diffusion and Balanced scorecard with	• Technology advantage and competition intensity moderate the relation between IS diffusion and balanced scorecard • Organizational Support partially moderates the relation between IS diffusion and balanced scorecard
Lin (2014)	TFSC	Simultaneous	Determinants of electronic supply chain management (e-SCM) adoption	• Perceived benefits, top management support, absorptive capacity, competitive pressure → adoption of e-SCM • Perceived Cost negatively → adoption of e-SCM • Trading Partner Influence and Firm size does not → the adoption of e-SCM
Hsu et al. (2014)	IJIM	Simultaneous	Determinants of Cloud Computing (CC) Adoption intention in Taiwan	• Perceived benefits, IT capability → adoption of CC • Business Concerns negatively → adoption of CC External pressure does not → adoption of CC
Ghobakhloo et al. (2011)	IM&DS	Simultaneous	Determinants of e-commerce adoption in SMEs in Iran	• Business size, relative advantage, compatibility, buyer-supplier pressure, vendor support, competition, CEOs IS knowledge and innovativeness → adoption of e-commerce • Cost and information intensity do not → adoption of e-commerce
Cruz-Jesus et al. (2019)	CII	Simultaneous	Antecedents that effect CRM adoption stages (evaluation, adoption, routinization)	• Technology competence → CRM adoption • Technology competence does not → CRM evaluation and routinization • Data quality and Integration → CRM evaluation and adoption • Data quality and Integration does not → CRM routinization • Top management support → CRM evaluation and adoption • Competitive pressure → CRM evaluation and routinization • Competitive pressure does not → CRM adoption

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Author & Year	Journal	TOE Contexts	Focus of Study	Findings ("→" = lead(s) to)
Oliveira et al. (2019)	IJIM	EC moderates relation between OC TC and SaaS adoption	Examine the contextual factors that influence the adoption of SaaS	• Technology competence, top management support, environmental context, → SaaS adoption • Environmental context moderates the relation between technology competence and SaaS adoption • Environmental context does not moderate the relation between top management support and SaaS adoption
Wang and Lo (2016)	GIQ	Simultaneous	Determinants of Open Government Data (OGD) adoption	• Perceived benefits, organization readiness and external pressure → OGD adoption • Perceived barriers do not → OGD adoption
Wei et al. (2015)	I&M	Simultaneous	Antecedents of RFID assimilation into these Chinese companies	• Relative advantage, complexity, and competition do not → RFID assimilation • IT Infrastructure, managerial capability and absorptive capacity → RFID assimilation • Environmental uncertainty negatively → RFID assimilation
Chen et al. (2015)	JMIS	Simultaneous	Identify factors that impact usage of Big Data Analytics (BDA) in firms	• Expected benefits, technological compatibility, top management support, organization readiness, competitive pressure → BDA use
Gutierrez et al. (2015)	JEIM	Simultaneous	Factors influencing managers' decision to adopt cloud computing (CC)	• Technology readiness, competition and trading partner pressure → adoption of CC • Complexity negatively → adoption of CC • Top management support, relative advantage, firm size, compatibility does not → adoption of CC
Kuan and Chau (2001)	I&M	Simultaneous	Identifying factors for small business EDI adoption	• Perceived direct benefits, technical competence and government pressure → EDI adoption • Perceived indirect benefits do not → EDI adoption • Cost and industry pressure negatively → EDI adoption
Lian et al. (2014)	IJIM	Simultaneous	Investigate factors affecting the adoption of cloud computing technology (CCT) in Taiwanese hospitals	• Data security → adoption of CCT • Perceived technical competence → adoption of CCT • Top managers support → adoption of CCT • Adequate resources → adoption of CCT • Complexity → adoption of CCT • Perceived industry pressure does not → adoption of CCT
Martins et al. (2016)	CHB	Simultaneous	Factors effecting SaaS diffusion	• Relative advantage, complexity, technology competence, top management support, normative pressure → SaaS diffusion • Compatibility, coercive and mimetic pressure do not → SaaS diffusion
Oliveira et al. (2014)	I&M	Simultaneous	Determinants of Cloud Computing (CC) adoption in the manufacturing and services sector	**Manufacturing Firms** • Relative advantage, technology readiness, firm size → adoption of CC • Complexity and compatibility, management support and competition do not → adoption of CC **Service Firms** • Complexity and compatibility, technology readiness, top management support, firm size, technology readiness → adoption of CC • Relative advantage, Competitive pressure and regulatory support do not → adoption of CC
Pan and Jang (2008)	JCIS	Simultaneous	Determinants of ERP adoption in Taiwan's communication industry	• IT infrastructure, competition, regulatory policy does not → ERP adoption • Perceived barriers negatively → ERP adoption • Production and operations improvement, firm size, technology readiness → ERP adoption
Puklavec et al. (2018)	IM&DS	Simultaneous	Determinants of Business Intelligence (BI) adoption	• Relative advantage, management support, rational decision-making culture, organization data environment, external pressure does not → BI adoption • Project champion, cost and organization readiness → BI adoption
Masood and Egger (2019)	RCIM	Simultaneous	Identify critical success factors for Augmented Reality (AR) implementation	• System configuration, technology hardware readiness, compatibility, organization fit → AR Implementation • External support and user barrier do not → AR Implementation
Haneem et al. (2019)	IJIM	Simultaneous	Determinants of Master Data Management (MDM) adoption by local government	• Data quality, governance, technology competence, citizen demand and management support → MDM adoption • Data security, relative advantage and government policy do not → MDM adoption
Sun et al. (2018)	JCIS	Simultaneous	Main factors affecting the organizational adoption of big data	• Relative advantage, human and technology resources, management support, complexity, technology and trading partner readiness, market turbulence → big data adoption • Cost of adoption negatively → big data adoption
Chandra and Kumar (2018)	JECR	Simultaneous		

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Author & Year	Journal	TOE Contexts	Focus of Study	Findings ("→" = lead(s) to)
			Factors influencing Augmented Reality (AR) adoption by e-commerce firms	• Technological competence, relative advantage, management support, consumer readiness → AR adoption • Decision-makers knowledge does not → AR adoption
Tsou and Hsu (2015)	IJIM	Simultaneous	Role of TOE openness in service coproduction	• The openness of technology does not → service coproduction • Openness of corporate culture and external environment → service coproduction
Darbanhosseiniamirkhiz and Wan Ismail (2012)	JTIM	Simultaneous	Critical factors for Advanced Manufacturing Technology (AMT) adoption	• External pressure, supplier support, financial resources, organization structure, culture, manufacturing strategy, HR practices, management support, perceived benefits and technology in use will → AMT adoption

Note: IJPR: International Journal of Production Research, IJIM: International Journal of Information Management, TFSC: Technological Forecasting and Social Change, JMIS: Journal of Management Information Systems, GIQ: Government Information Quarterly, PPC: Production Planning and Control, I&M: Information and Management, CHB: Computers in Human Behaviour, JEIM: Journal of Enterprise Information Management, IJHCI: International Journal of Human Computer Interaction, IM&DS: Industrial Management and Data Systems, CII: Computers in Industry, JCIS: Journal of Computer Information Systems, JECR: Journal of Electronic Commerce Research, RCIM: Robotics and Computer Integrated Manufacturing, JTIM: Journal of Technology and Innovation Management.

Appendix A3. Salient studies depicting the relation between manufacturing technologies and performance

Author & Year	Journal	Relevant constructs	Findings
Beaumont and Schroder (1997)	Technovation	Use of AMT, performance	AMTs negatively impacts performance whereas TQM, EDI and LAN positively impact performance.
Bourke and Roper (2016)	Technovation	AMT adoption, firm innovation	CNC machines weakly impact innovation while robotics has a strong impact on innovation performance.
Brandyberry et al. (1999)	DS	AMT implementation, intermediate performance outcomes	AMTs enhance the production process integration but do not impact market-oriented flexibility and administrative intensity.
Cheng et al. (2018)	IJPE	AMT Investments, performance outcomes	Maintaining certain threshold of AMTs investment improves manufacturing performance
Das and Jayaram (2003)	IJPR	AMT, performance, contingency variables	The relation between AMTs and performance is contingent upon lean manufacturing and work organization practices.
Zhang et al. (2006)	IJOPM	AMT, Flexible Manufacturing Competence, Operational improvement	AMTs impact flexible manufacturing competence when operational improvement practices are being implemented.
Swamidass and Kotha (1998)	JOM	Manufacturing Technology, firm size, performance	AMTs use is not directly linked to performance rather the relation is weakly moderated by firm size.
Raymond and St-Pierre (2005)	IJOPM	Advanced Manufacturing Systems (AMS), performance	The sophistication of AMS significantly impacts the operational and business performance of SMEs.
Zelbst et al. (2012)	IJOPM	RFID, Supply Chain performance, Organizational Performance	RFID improves the supply chain and organizational performance through manufacturing efficiency and effectiveness.
Zelbst et al. (2010)	MRR	RFID, Operational Performance	RFID improves the operational performance of the firm; reduces inventory cost, operating cost, increases throughput and due date performance.

Note: RFID: Radio Frequency Identity Device, AMT: Advanced Manufacturing Technology, TQM: Total Quality Management, EDI: Electronic Data Interchange, LAN: Local Area Network, DS: Decision Sciences, IJPE: International Journal of Production Economics, IJPR: International Journal of Production Research, IJOPM: International Journal of Operations and Production Management, MRR: Management Research Review, JOM: Journal of Operations Management.

Appendix B. Measurement model indicators

Measurement Item	Factor Loadings
Organizational Context (AVE = 0.495, Cronbach α = 0.833, CR = 0.854)	
1. Delegation and knowledge of your workers (e.g. empowerment, training, encouraging solutions to work-related problems, pay for competence or incentives for improvement results)	0.703
2. Open communication between workers and managers (information sharing, encouraging bottom-up open communication, two-way communication flows)	0.662
3. Lean organization (e.g. few hierarchical levels and a broad span of control)	0.673
4. Continuous improvement programs through systematic initiatives (e.g. kaizen, improvement teams, improvement incentives)	0.683
5. Autonomous teams (e.g. team responsible for planning, execution, and control, workers sharing experience, knowledge, and skills, formalization of team composition and responsibilities, workgroup incentives)	0.736
6. Workers flexibility (e.g. multi-tasking, multi-skilling, job rotation)	0.610
7. Use of flexible forms of work (e.g. temporary workers, part-time, job sharing, variable working hours)	a
Technological Context (AVE = 0.545, Cronbach α = 0.776, CR = 0.778)	
8. Technological integration between product development and manufacturing through e.g. CAD-CAM, CAPP, CAE, Product Lifecycle Management	0.735
9. Integrating tools and techniques, such as Failure Mode and Effect Analysis, Quality Function Deployment, and Rapid Prototyping	0.780
10. Communication technologies such as teleconferencing, web-meetings, intranet and social media	0.665
Environmental Context (Composite Indicator)	
11. The rate of Technological Change	
12. Competitive Rivalry	
13. The threat of Product Substitution	
14. Bargaining Power of customers	
DMTs' Implementation (AVE = 0.505, Cronbach α = 0.792, CR = 0.801)	
15. Use of advanced processes, such as laser and water cutting, 3D printing, high precision technologies	0.617

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Measurement Item		Factor Loadings
16.	Development towards "the factory of the future" (e.g. smart/digital factory, adaptive manufacturing systems, scalable manufacturing)	0.798
17.	Engaging in process automation programs (e.g. automated machine tools and handling/transportation equipment, robots)	0.728
18.	Engaging in product/part tracking and tracing programs (barcodes, RFID)	0.597
Operational Performance (AVE = 0.636, Cronbach α = 0.791, CR = 0.839)		
19.	Flexibility Performance	0.700
20.	Design Performance	0.861
21.	Delivery Performance	0.736
22.	Quality Performance	0.809
Flexibility Performance (AVE = 0.585, Cronbach α = 0.736, CR = 0.738)		
23.	Mix Flexibility	0.755
24.	Volume Flexibility	0.773
Delivery Performance (AVE = 0.689, Cronbach α = 0.812, CR = 0.816)		
25.	Delivery Speed	0.809
26.	Delivery Reliability	0.821
Design Performance (AVE = 0.44, Cronbach α = 0.607, CR = 0.607)		
27.	New product introduction ability	0.693
28.	Product customization ability	0.622
Quality Performance (AVE = 0.656, Cronbach α = 0.791, CR = 0.792)		
29.	Product Quality	0.812
30.	Conformance Quality	0.818

a: Aborted items, AVE: Average variance extracted, CR: Composite Reliability.

Appendix C. Questionnaire

Table CI
Questions related to the Environmental Context.

Environmental Context	Environment in which business unit operates						
Rate of Technological Change	Very Low	1	2	3	4	5	Very High
Competitive Rivalry within Industry	Very Low	1	2	3	4	5	Very High
Threat that your products will become substituted	Very Low	1	2	3	4	5	Very High
Bargaining power of customers	Very Weak	1	2	3	4	5	Very Strong

Table CII
Questions related to the Organizational Context.

Organizational Context	Current Level of Implementation				
	None				High
New Forms of Work Organization					
Delegation and knowledge of your workers (e.g. empowerment, training, encouraging solutions to work related problems, pay for competence or incentives for improvement results)	1	2	3	4	5
Lean organization (e.g. few hierarchical levels and broad span of control)	1	2	3	4	5
Continuous improvement programs through systematic initiatives (e.g. kaizen, improvement teams, improvement incentives)	1	2	3	4	5
Workers flexibility (e.g. multi-tasking, multi-skilling, job rotation)	1	2	3	4	5
Use of flexible forms of work (e.g. temporary workers, part time, job sharing, variable working hours)	1	2	3	4	5
Collaborative Climate					
Autonomous teams (e.g. team responsible for planning, execution and control, workers sharing experience, knowledge and skills, formalization of team composition and responsibilities, work group incentives)	1	2	3	4	5
Open communication between workers and managers (information sharing, encouraging bottom-up open communication, two-way communication flows)	1	2	3	4	5

Table CIII
Questions related to Technological Context.

Technological Context	Current Level of Implementation				
	None				High
Design and Production Technologies					
Design integration between product development and manufacturing through e.g. platform design, standardization and modularization, design for manufacturing, design for assembly	1	2	3	4	5
Technological integration between product development and manufacturing through e.g. CAD-CAM, CAPP, CAE, Product Lifecycle Management	1	2	3	4	5
Integrating tools and techniques, such as Failure Mode and Effect Analysis, Quality Function Deployment, and Rapid Prototyping	1	2	3	4	5
Information and Communication Technologies					
Communication technologies such as teleconferencing, web-meetings, intranet and social media	1	2	3	4	5

Table CIV
Questions related to the Digital Manufacturing Technologies (DMTs) Implementation.

DMTs' Implementation	Current Level of Implementation				
	None				High
Use of advanced processes, such as laser and water cutting, 3D printing, high precision technologies	1	2	3	4	5
Development towards "the factory of the future" (e.g. smart/digital factory, adaptive manufacturing systems, scalable manufacturing)	1	2	3	4	5
Engaging in process automation programs (e.g. automated machine tools and handling/transportation equipment, robots)	1	2	3	4	5
Engaging in product/part tracking and tracing programs (bar codes, RFID)	1	2	3	4	5

Table CV
Questions related to Operational Performance.

Operational Performance	Relative to our main competitors, our performance is				
	much lower		Equal	much higher	
Flexibility					
Mix Flexibility	1	2	3	4	5
Volume Flexibility	1	2	3	4	5
Delivery					
Delivery Speed	1	2	3	4	5
Delivery Reliability	1	2	3	4	5
Design					
New Product Introduction Ability	1	2	3	4	5
Product Customization Ability	1	2	3	4	5
Quality					
Product Quality	1	2	3	4	5
Conformance Quality	1	2	3	4	5

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