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Open innovation in the manufacturing industry: A review and research agenda

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ABSTRACT

In today's competitive world, globalization touches all industries. The open innovation (OI) paradigm has garnered increasing importance in academic research and industrial applications. Considering this interest, this paper aims to synthetize up-to-date findings, outline the intellectual structure of OI within the manufacturing research domain, and suggest a future research agenda. Building upon the content analysis of 239 articles indexed in Web of Science and Scopus databases, using homogeneity analysis by means of alternating least squares (HOMALS), this study reveals the theoretical underpinnings, research trends, and methodologies of this research field. Our analysis revealed that the study of sustainability, commitment-based human resource practices, and Industry 4.0 (I40) represent important future research streams for OI in the manufacturing industry. In collaborating throughout the supply chain, manufacturing firms could minimize production waste, ensure better working conditions, and adapt business models. In the "new normal" posed by the COVID-19 pandemic, it is more important than ever to study the effects of managerial competencies, employee training and development, and reward systems on open cultures in manufacturing firms. This study goes on to outline research opportunities in I40, particularly regarding knowledge exchange and technology transfer among partners and OI's influence on the adoption of I40 technologies.

1. Introduction

The ongoing globalization and exponential growth of technological intensity (Gassmann, 2006; Chesbrough and Bogers, 2014) has increased the importance of - and necessity for - open innovation (OI) (Mitchell and Singh, 1996; Ghobakhloo and Fathi, 2019), which has been recognized as an essential part of one of the United Nations Sustainable Development Goals for 2030 (UN General Assembly, 2015; Smart et al., 2019). Simultaneously, the manufacturing industry, stimulated by globalization, has begun to invest further in OI in order to improve productivity and meet customer demands (Fajsi et al., 2016; Wang and Islam, 2017). Accordingly, the importance of OI and the acknowledgment that capable and intelligent minds exist outside of the firm has captured the attention of a large number of companies, venture capitalists, and governments around the globe who have subsequently provided additional funding opportunities (Chesbrough and Vanhaverbeke, 2018). From a strategic perspective, the expansion of available OI funding enabled companies to rethink the ways in which ideas are generated, fully embracing the era of OI (Alassaf et al., 2020).

The paradigm of OI has developed over the years and this has encouraged practitioners and researchers to study this topic from different perspectives. Furthermore, technological development and ongoing digital disruption has transformed the manufacturing industry, meaning that it is no longer seen as complex and mature. Accordingly, the manufacturing industry has begun to expand its horizons and adapt its business models. For example, P&G adopted an OI approach and developed a new strategy which ultimately led to new products incorporating elements of ideas from outside of the company (Dodgson et al., 2006). Next, NASA managers, stimulated by the reduction of a budget, created a new strategy focusing on collaboration. They sourced OI practices through a prize-winning competition and through crowdsourcing, which resulted in innovation and a new and adaptable business model (Davis et al., 2015).

Considering the importance of OI and the necessity of collaborating with all stakeholders, this paper complements the up-to-date stock of knowledge on OI (Kovács et al., 2015) by addressing the theoretical

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approaches, major research themes, methodological approaches, geographical scope, and industries underpinning OI research in a manufacturing context. In order to do so - and in line with the systematic literature review guidelines (Paul and Rialp-Criado, 2020) - the initial planning phase involved the formulation of research questions (RQs), creating review protocols, outlining the rules of the research, establishing a strategy for data extraction, and integrating the stages of the extracted data (Snyder, 2019). As such, this study sought to compile and categorize the application of OI in the context of the manufacturing industry by answering the following RQs:

RQ1: What are the underlying theoretical approaches, major research themes, geographical scopes, methodological approaches, and industries in open innovation in the manufacturing research field?

RQ2: What are the future research streams for open innovation in a manufacturing context, in terms of theoretical and practical approaches?

Previous literature reviews, in most cases, adopt a citation-based approach (Kovács et al., 2015), in which they compile published articles, acknowledge influential authors in the research domain, and outline notable references, institutions, etc. However, although valuable and insightful (Zupic and Čarter, 2015), this approach lacks the richness of experts' insights and content analyses (Furrer et al., 2020). Hence, in order to address these RQs, this study uses a content analysis approach by means of Multiple Correspondence Analysis (MCA). This approach enables researchers to synthetize up-to-date findings and graphically depict the intellectual structure of the research field. The advantages of this approach arise from the combination of an expert-based approach and content analysis (Furrer et al., 2020). This method is widely used when mapping fields and has been used to assess strategic management (Furrer et al., 2008), multinational enterprises (Dabić et al., 2014), international alliances and culture (López-Duarte et al., 2016), cross-border mergers and acquisition (Kiessling et al., 2019), and the internationalization of small and medium firms (Dabić et al., 2019). Unlike other text mining approaches, MCA is based on the homogeneity analysis by means of alternating least squares (HOMALS), which allows researchers to analyze content, form clusters based on former literature reviews and findings, and group the categories into dimensional spaces while anticipating the deduced insights on the relationships between categories.

This study contributes to current understandings of OI in manufacturing by consolidating previous research, proposing research opportunities, and providing recommendations for practitioners. This study interprets the role of OI in the manufacturing research domain and acknowledges contemporary research trends, such as *collaboration, open strategy, breadth, depth,* and *innovation from the firm's perspective*. Additionally, this study integrates theoretical approaches (e.g., *institutional theory, knowledge-based view, resource-based view, supply chain management,* and *transactional cost economics theory*) and proposes future research avenues regarding *sustainability, commitment-based HR practices,* and *Industry 4.0*. Moreover, the summary of the research domain offers practitioners a set of recommendations with regards to overcoming challenges pertaining to the adoption and employment of OI practices in manufacturing.

This remainder of this paper is structured as follows. The next section will outline the development of the OI paradigm over the years. The following section summaries the methodology and the systematic literature review procedure. In the fourth section, the descriptors used when mapping are explained in detail. In the fifth section, the proposal for the future research have been made. Finally, in the last section, contributions to practice and theory are outlined and concluding remarks are given.

2. Open innovation

Since Chesbrough's (2003) seminal work, scholarly awareness of OI has increased exponentially, resulting in more than 4,000,000 documents indexed on Google Scholar in 2020. Chesbrough stated that "*… valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well*" (Chesbrough, 2003, p. 43). Building upon Chesbrough's remarks on the OI paradigm (2003, p. 43), OI research has advanced over the years. In 2014, Chesbrough and Bogers (2014, p. 33) expanded upon OI's initial conceptualization, providing up-to-date definition: "*a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model*". The evolution of the OI concept is presented in Table 1.

Several authors have assessed OI findings and have highlighted the necessity for further explorations of OI perspectives in theory and practice. For example, Gassmann and colleagues (2010) contributed to OI's phenomena by organizing the research field and revealing gaps, emphasizing the importance of patents and intellectual property. Furthermore, these authors demonstrated the relevance of studying OI in SMEs, accentuating the effect of OI on virtual R&D teams. Next, building upon the development of the OI paradigm and growing interest among academics and practitioners, Chesbrough and Bogers (2014) depicted the scope of academic literature since the term 'open innovation' was coined in 2003. In their seminal paper, Chesbrough and Bogers advanced the definition of OI by introducing pecuniary and non-pecuniary mechanisms of inbound and outbound OI and

Table 1
Evolution of the open innovation concept.

Author	Definition
Chesbrough (2003, p. 43)	*"… valuable ideas can come from inside or outside the company and can go to market from inside or outside the company as well".*
Gassmann and Enkel (2004, p. 2)	*"Open innovation means that the company needs to open up its solid boundaries to let valuable knowledge flow in from the outside in order to create opportunities for co-operative innovation processes with partners, customers and/or suppliers. It also includes the exploitation of ideas and IP in order to bring them to market faster than competitors can".*
Chesbrough (2006, p. 1)	*"Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively".*
Laursen and Salter (2006, p. 43)	*"An open innovation model is using a wide range of external actors and sources to help them achieve and sustain innovation".*
West and Gallagher (2006, p. 320)	*"We define open innovation as systematically encouraging and exploring a wide range of internal and external sources for innovation opportunities, consciously integrating that exploration with firm capabilities and resources, and broadly exploiting those opportunities through multiple channels".*
Lichtenhaler (2008, p. 148)	*"An open innovation approach refers to systematically relying on a firm's dynamic capabilities of internally and externally carrying out the major technology management tasks, i.e., technology acquisition and technology exploitation, along the innovation process. Thus, open innovation processes involve a wide range of internal and external technology sources, and a wide range of internal and external technology commercialization channels".*
Lichtenhaler (2011, p. 77)	*"Open innovation is defined as systematically performing knowledge exploration, retention, and exploitation inside and outside an organization's boundaries throughout the innovation process".*
Chesbrough and Bogers (2014, p. 33)	*"We define open innovation as a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model".*

highlighting the importance of the firm's business model. More recently, Bogers and colleagues (2017) formed an integrative framework of the levels of analysis for OI research. They contributed to the development of the paradigm by presenting future research opportunities at micro, meso, and macro levels of analysis (e.g., from individual challenges to applications of OI at an industry or national level). Overall, these scholars demonstrated that it is important to study the role and the application of OI in a manufacturing context, thus reiterating the necessity of our study.

3. Methodology

3.1. The sample of articles and data collection

In order to complement contemporary findings related to OI, this research investigates the span of OI with regards to the manufacturing industry, which has not been thoroughly explored. Hence, the goal of this systematic literature review is to map and synthetize the field of OI in the manufacturing industry and subsequently offer future research streams. The first step involved the selection of articles to be analysed. This search was conducted among publications indexed in the well-known scientific databases of Elsevier Scopus, Thomas Reuters Social Sciences Citation Index (SSCI), and Science Citation Index Expanded (SSCI). For a publication to be considered, two conditions were required: it should contain the term *"open innovation"* AND *"manufact*"* in one of the following fields: title, abstract, and/or keywords (Kiessling et al., 2019). After searching for articles, an initial database of 397 articles was obtained. Following this, all duplicates were deleted. Some articles were published in both databases and so, for consistency, duplicates from Scopus were eliminated. The third step involved reading all of the articles and removing those that did not fit the aim of the study. The criteria for accepting articles were: (1) the main topic of the article should be OI and articles dealing only with 'innovation' or 'closed innovation' were to be excluded; and (2) some articles explained the difference between OI in manufacturing and the service industry; articles with sampling proportions (in terms of sector) of more than 50% manufacturing were included, and articles mainly dealing with the service sector were excluded. A team of three international researchers separately determined whether or not each article should be excluded or included (Graneheim and Lundman, 2004). Following the results of the revision, the researchers discussed their findings and made the final decision. In the following section, the fifth step is outlined in detail. Fig. 1 shows the literature review procedure.

Ultimately, a total of 239 articles were selected. Articles dealing with this topic were published between 2003 and 2019, which was not surprising as the term *"open innovation"* has been developing since the publication of Chesbrough's book in 2003. The period of publication for the articles included in this review was between 2003 and 2019, with the following distribution: 3.77% from 2003 to 2009; 30.96% from 2010 to 2014; and 65.27% from 2015 to 2019. This distribution shows the increasing interest in the area of OI in the manufacturing industry among researchers and practitioners (see Fig. 2), providing support for conducting the review (Tranfield et al., 2003).

The growing number of OI publications and the increased degree of

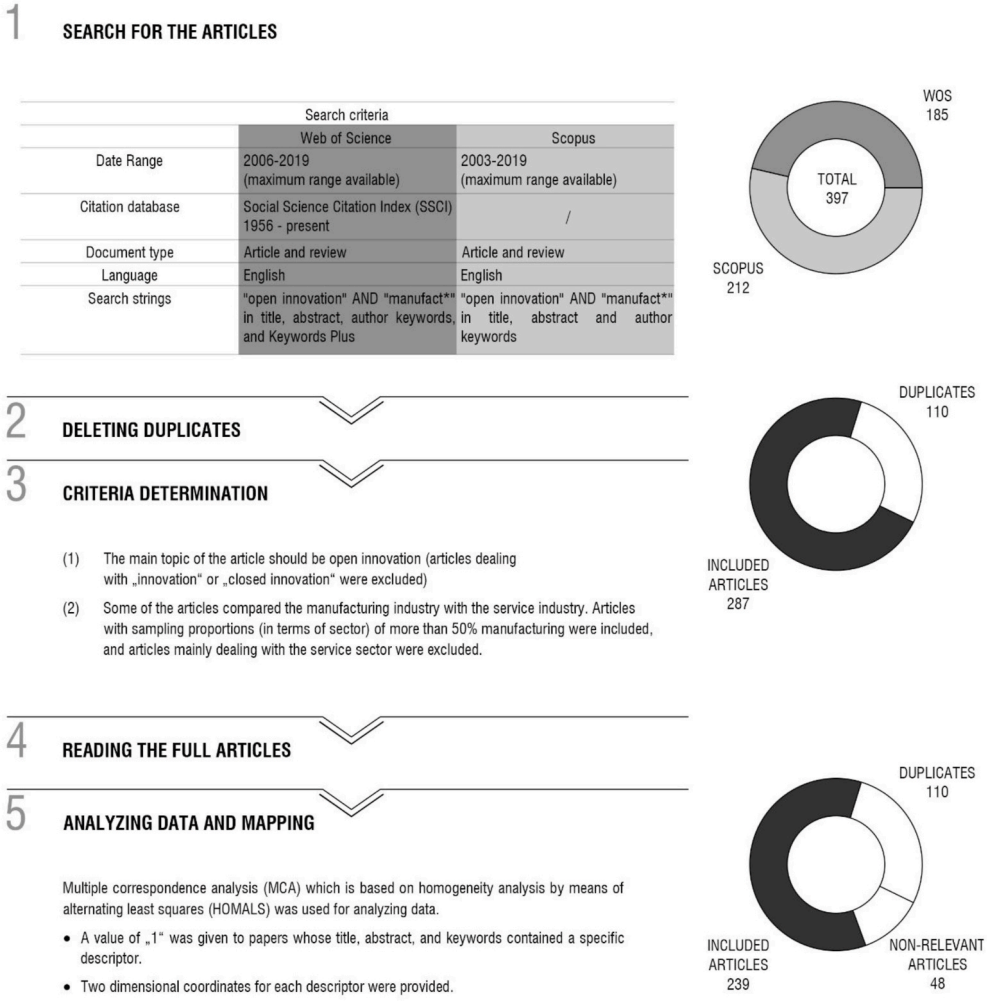

Fig. 1. Literature review procedure.

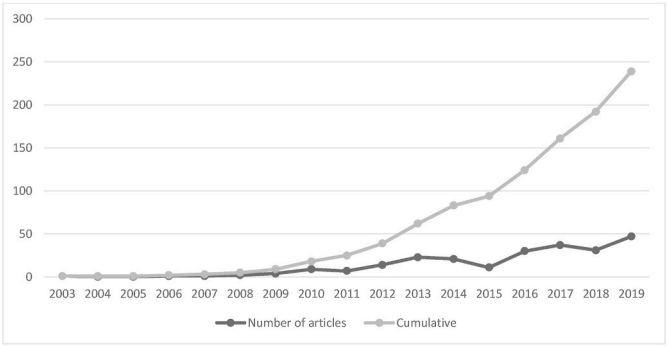

Fig. 2. Number of articles per year.

interest among practitioners was further supported by special issues published in renowned academic journals, such as *R&D Management, IEEE- Transactions on Engineering Management, Technovation, Research Policy and Research-Technology Management*, among others.

3.2. The HOMALS procedure for multiple correspondence analysis (MCA)

To analyze the data, we used multiple correspondence analysis (MCA) based on homogeneity analysis by means of alternating least squares (HOMALS) (Hoffman and De Leeuw, 1992). MCA can be seen as *"a way of analyzing a subject by variable matrix with categorical variables or a subject by item matrix of multiple-choice data"* (Tenenhaus and Young, 1985, p. 91). Accordingly, a HOMALS method enables the analysis of the causal relations between the descriptors (González-Loureiro et al., 2014; Dabić et al., 2014). To form an initial list of keywords and descriptors, previous literature reviews investigating OI from different perspectives - such as OI in small- and medium-sized enterprises (SMEs) (Torchia and Calabro, 2019), OI models (Lazzarotti et al., 2010), negotiation in OI (Barchi and Greco, 2018), and collaborative based HRM practices (Hong et al., 2019) - were used. Building upon the initial list and the content analysis of 239 articles, performed using QDA Miner v.5 and Wordstat v.8 software, the final list of keywords (i.e. the codebook) consisted of 1101 keywords (see Table 6, available in the supplementary material) which were categorized into 27 groups. The 27 groups, belonging to theoretical approaches, major research themes, geographical scope, methodology, and industry, were studied thoroughly in order to better understand the connections between them. An overview of the keywords, according to the major categories, is presented in the supplementary material (see Tables 1–5, available in the supplementary material).

Each of the 239 cases were given a binary value for each of the descriptors. A value of '1' was given to papers whose title, abstract, and keywords contained a specific descriptor. The HOMALS analysis was performed using SPSS v26. software. This procedure was used to provide an approximation of the two-dimensional coordinates of each descriptor. The result of this exploration was a *"proximity map where descriptors and articles are depicted in a low-dimensional space with two axes"* (López-Duarte, 2016, p. 517). The low-dimensional map, formed by the two first dimensions, shows that dimension one accounts for 9.65% and dimension two accounts for 18.28% of the explained variance (see Fig. 3). The map fits 27 variables into only two dimensions, causing a lower value of total variance (Lopez-Duarte et al., 2016). Following the recommendations of Hair and colleagues (1998, 2010) and Furrer and colleagues (2008, 2020), the validity and robustness of the MCA is better accessed through an overall keyword mean per article estimate, which should be greater than 1. In our case, the overall keyword mean per article was 1.21 per article, implying the fulfilment of this recommendation in performing a multivariate approach.

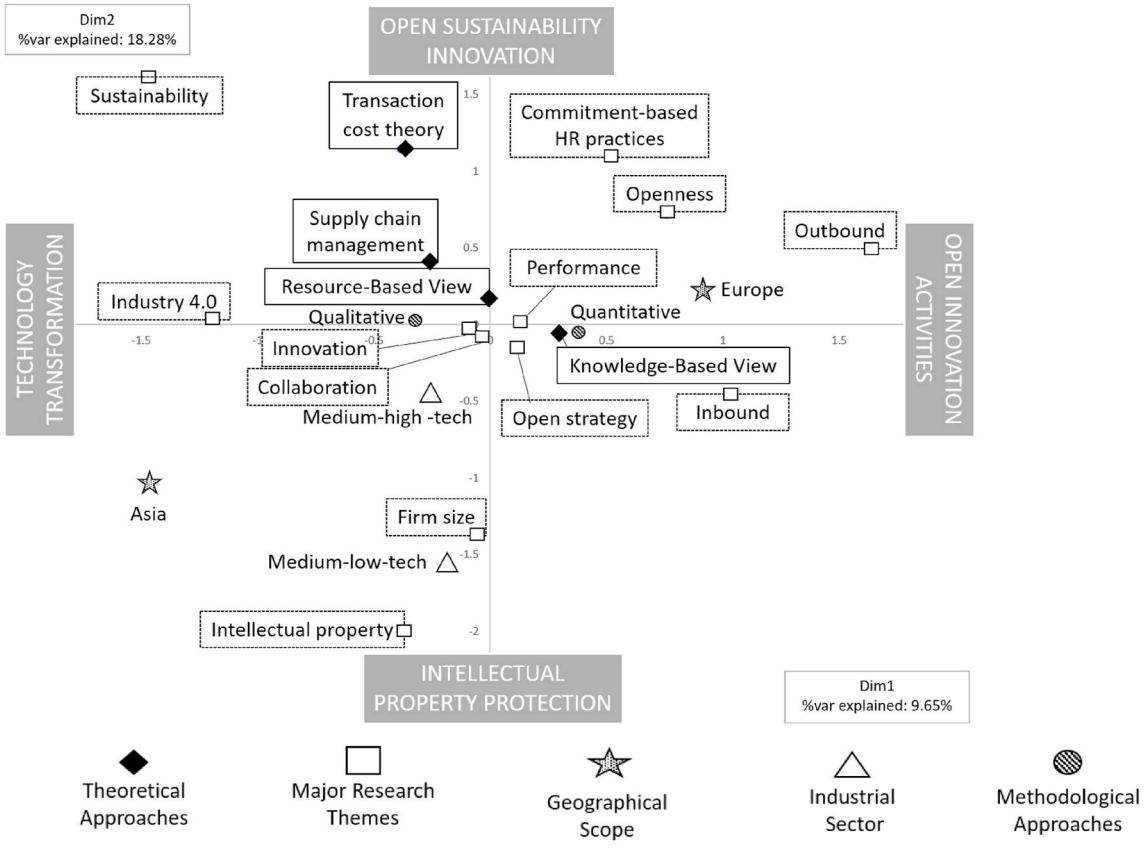

Fig. 3. Mapping open innovation in the manufacturing industry.

In order to ensure the clarity and readability of the map, the authors adopted a threshold condition of 6% frequency for the descriptors to be shown on the map. As a result of this rule, five descriptors were not shown on the map. Most of these descriptors were from the geographical scope category (Africa, North America, Oceania, and South America) and one was from the provision of theoretical foundations (Institutional theory). These descriptors are explored throughout the manuscript and are considered to be potential paths for future research.

3.3. Mapping open innovation in the manufacturing industry

Building upon the guidelines of Hoffman and De Leeuw (1992) and, more recently, López-Duarte (2016), the first stage when clarifying the results obtained through the HOMALS analysis (see Fig. 3) is the labelling of poles. According to López-Duarte et al. (2016, p. 515), the poles *"should be labelled according to the most-extreme-located descriptors, but also considering that the most frequent descriptors. Therefore, the label should combine both issues"*. Thus, to categorize poles, the most relevant descriptors were considered (López-Duarte et al., 2016; Kiessling et al., 2019). The descriptors positioned on the upper side of axis X shaped the label of the pole on that side. For example, inbound and outbound activities were often studied within the context of the knowledge-based view, using a quantitative approach and examining manufacturing firms based in Europe (Bianchi et al., 2016; Burchart et al., 2017). These descriptors formed the pole OI activities. In line with this, Table 2 shows the descriptors representing the poles of the axes, the keywords which best describe the poles, and the notable references (Table 3).

The left side of the map represents technological transformation. Articles located on this side dealt with the study of Industry 4.0 (the fourth industrial revolution) and an era of digital transformation. They were connected to a medium-high-tech industry (Fernandez et al., 2016; Kim and Kim, 2018). The right side of the map represents descriptors associated with OI activities: inbound and outbound. Some of the authors researched inbound and outbound activities separately (Bianchi et al., 2016), while others studied it together (Burcharth et al., 2017; Kim et al., 2016) in order to assess the ways in which they influence, for example, the performance of a manufacturing company (Cruz-González et al., 2015).

Articles at the top of the map deal with the study of open sustainability innovation (Cappa et al., 2016). In recent years, firms have become increasingly more concerned with economic, social, and environmental sustainability. The descriptor 'sustainability' is connected to transaction cost theory, as firms attempt to minimize the cost of their production and transportation in an effort to become more sustainable. Commitment-based HR practices are also a part of this cluster. For employees to accept innovations and collaborations with external parties, it is crucial to establish the correct culture in a company. It is vital that firms share information and knowledge within their society and thus become more socially sustainable. The bottom of the map shows articles connected to intellectual property, medium-low-tech industries, and firm size. Intellectual property represents a paradox in

Table 3
Overview of future research avenues.

Research Theme	Future research avenues	RQs
1. Sustainability	Resource-based view	*RQ1: How can dynamic capabilities encourage more sustainable production?*
	Medium-low tech industry	*RQ2: How can open sustainability innovation reduce costs and improve time to market in the food and beverage industry?*
	New combinations of industries	*RQ3: How might the collaboration between biotechnology and the food and beverage industry reduce production waste and increase the use of renewable energies?*
	Geographical scope	*RQ4: How might collaboration between Western companies and companies based in Africa influence social sustainability?*
5. Commitment-based HR practices	Knowledge-based view	*RQ1: How can the knowledge transfer processes between a team and partners improve NPD performance, using inbound and outbound open innovation activities as mediators?*
	Implementation of the digital manufacturing	*RQ2: How can digital trust moderate the relationship between open innovation and NPD performance?*
		RQ3: How can the new required managerial skills (e.g. complex problem solving, critical thinking, and people management) influence collaboration across the whole supply chain?
	Qualitative approach	*RQ4: What is the role of HR management in creating an open innovation strategy in manufacturing?*
7. Industry 4.0	NPD performance	*RQ1: How can the implementation of additive manufacturing encourage outbound open innovation activities and, consequently, improve NPD performance?*
		RQ2: How can Industry 4.0 solutions open up new potential for collaboration in the pharmaceutical industry?
	Intellectual property	*RQ3: How does open innovation mediate the relationship between digital revolution and intellectual property rights?*
		RQ4: What kind of digital patents are the most beneficial when protecting digital business models in the manufacturing industry?

Table 2
Descriptors representing the poles of the axes.

Pole	Label	Descriptor	Notable References
Axis Y Upper	Open sustainability innovation	Sustainability, Transaction cost theory, Commitment-based HR practices, Supply chain management	Cappa et al. (2016) Arcese et al. (2014) Mustaquim and Nyström (2014) Yun and Yigitcanlar (2017)
Axis Y Lower	Intellectual property protection	Intellectual property, Medium-low-tech industries, Firm size	Gama (2018) Stefan and Bengtsson (2016); 2017
Axis X Upper	Open innovation activities	Inbound, Outbound, Openness, Knowledge-based view	Bianchi et al. (2016) Burchart et al. (2017) Kim et al. (2016)
Axis X Lower	Technology transformation	Industry 4.0, Medium-high-tech industries	Trantopoulos et al. (2017) Kastelli et al. (2018)

terms of OI, because firms want to share knowledge and innovation with external partners but, simultaneously, must defend themselves (Gama, 2018). Intellectual property is related to a firm's size and there are many articles dealing with the differences between patenting activities in SMEs in comparison to large firms. Stefan and Bengtsson (2016; 2017) explored the intellectual property protection mechanisms – formal, semi-formal, and informal. They concluded that different stages of the innovation process require different types of protection. In the following section, the descriptors and their positions on the map are explained in detail.

4. Intellectual structure OF OI IN the manufacturing research field

In order to synthetize OI in the manufacturing industry research field, the descriptors are arranged into five major categories: theoretical approaches, major research themes, geographical scope, methodological approaches, and industry. The categorization of these descriptors, according to these broad aspects, facilitates a better understanding of OI in the intellectual structure of the manufacturing field as it follows the good practices of the acknowledged literature reviews published in flagship journals (e.g. Kiessling et al., 2019; Furrer et al., 2020; Dabić et al., 2020). In order to outline the intellectual structure of OI in the manufacturing industry, Fig. 4 presents the visual division of major descriptors and their focused sub-topics. Additionally, in Fig. 4, notable references for each descriptor are presented, followed by a further explanation of the connections between them. Next, Fig. 5 shows the most used descriptors and their frequencies. For each category, the amount of papers using each theoretical approach, major theme, geographical scope, industry, and methodology can be seen.

4.1. Theoretical approaches

4.1.1. Institutional theory

Institutional theory delivers a valuable sight of organizations which is influenced by external sources (for example, state) as well as the organization itself (Zucker, 1987). The National System of Innovation is the key body when it comes to considering the ways in which nations differ in terms of their institutional support for innovation (West et al., 2005). Jung and Andrew (2014) used institutional frameworks to explore R&D collaborations between university research institutions and SMEs. Institutional theory is the least frequently used theoretical approach in this study and it is not shown on the map. Only 5% of articles have used this theory.

4.1.2. Knowledge-based view

Knowledge-based view is the most frequently employed theory in OI research within the manufacturing industry. Knowledge is the most significant resource and it often constitutes a firm's competitive advantage. In the manufacturing industry, where technology is changing every day, it is important for a firm to exchange knowledge and technology. Many authors focus their studies on absorptive capacity, which is associated with exploring external knowledge. Cohen and Levinthal (1990, p. 128) coined the term absorptive capacity as the *"ability to recognize the value of new information, assimilate it, and apply it to commercial ends"*. Xia and Roper (2016) went on to consider the connection between OI in small firms' absorptive capacity and external relationships. Organizations that search more widely and deeply will have

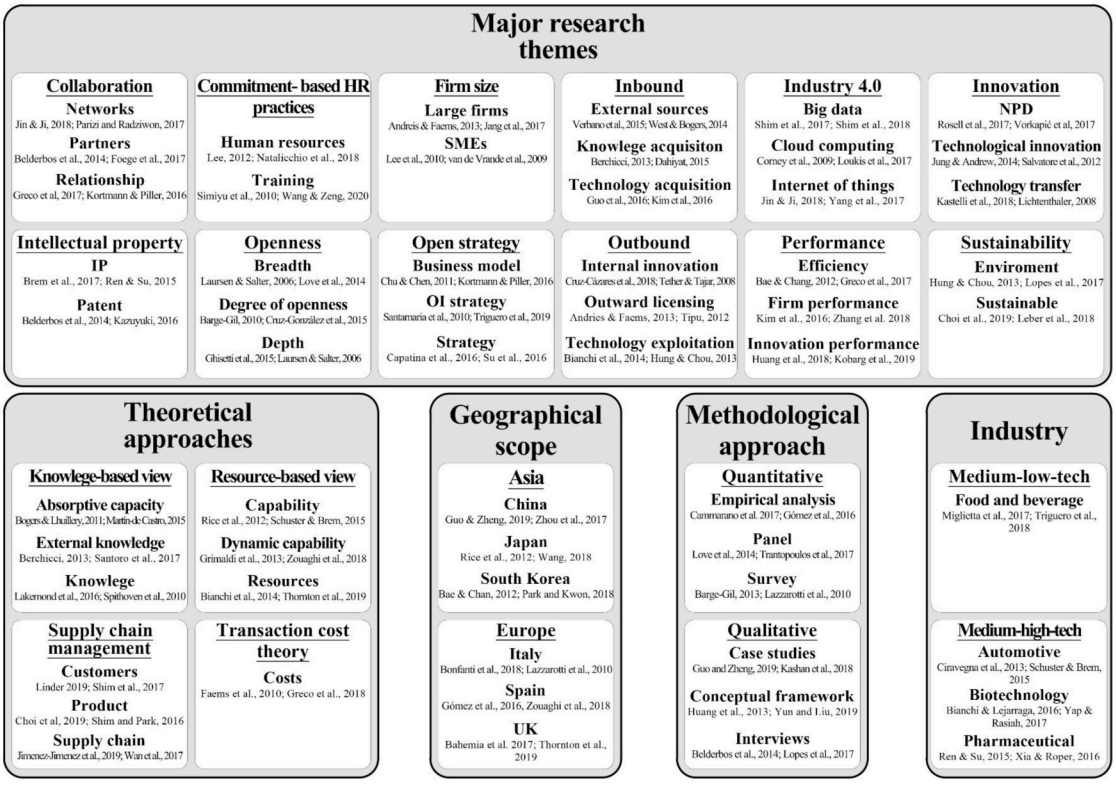

Fig. 4. Notable references regarding theoretical cornerstones, the research trends of OI, geographical scope, methodology, and industry (Bae and Chang, 2012; Belderbos et al., 2014; Bianchi et al., 2014; Bianchi and Lejarraga, 2016; Bogers and Lhuillery, 2011; Capatina et al., 2016; Carter and Rogers, 2008; Choi et al., 2019; Chu and Chen, 2011; Corney et al., 2009; Eftekhari and Bogers, 2015; Fleischmann et al., 2016; Foege et al., 2017; Ghisetti et al., 2015; Gomez et al., 2016; Hair et al., 1998, 2010; Jin and Ji, 2018; Kratzer et al., 2017; Lee, 2012; Linder, 2019; Loukis et al., 2017; Martín-de Castro, 2015; Natalicchio et al., 2018; Parizi and Radziwon, 2017; Rayna and Striukova, 2019; Rice et al., 2012; Rosell et al., 2017; Salvatore et al., 2012; Santoro et al., 2017; Shim et al., 2018; Spithoven et al., 2010; Su et al., 2016; Tether and Tajar, 2008; Thornton et al., 2019; Triguero et al., 2018; Vorkapić et al., 2017; Wan et al., 2017; Wang, 2018; Wang and Zeng, 2020; Yang et al., 2017; Yap and Rasiah, 2017; Zhang et al., 2018; Zhou et al., 2017; Zouaghi et al., 2018; Cheah and Ho, 2020).

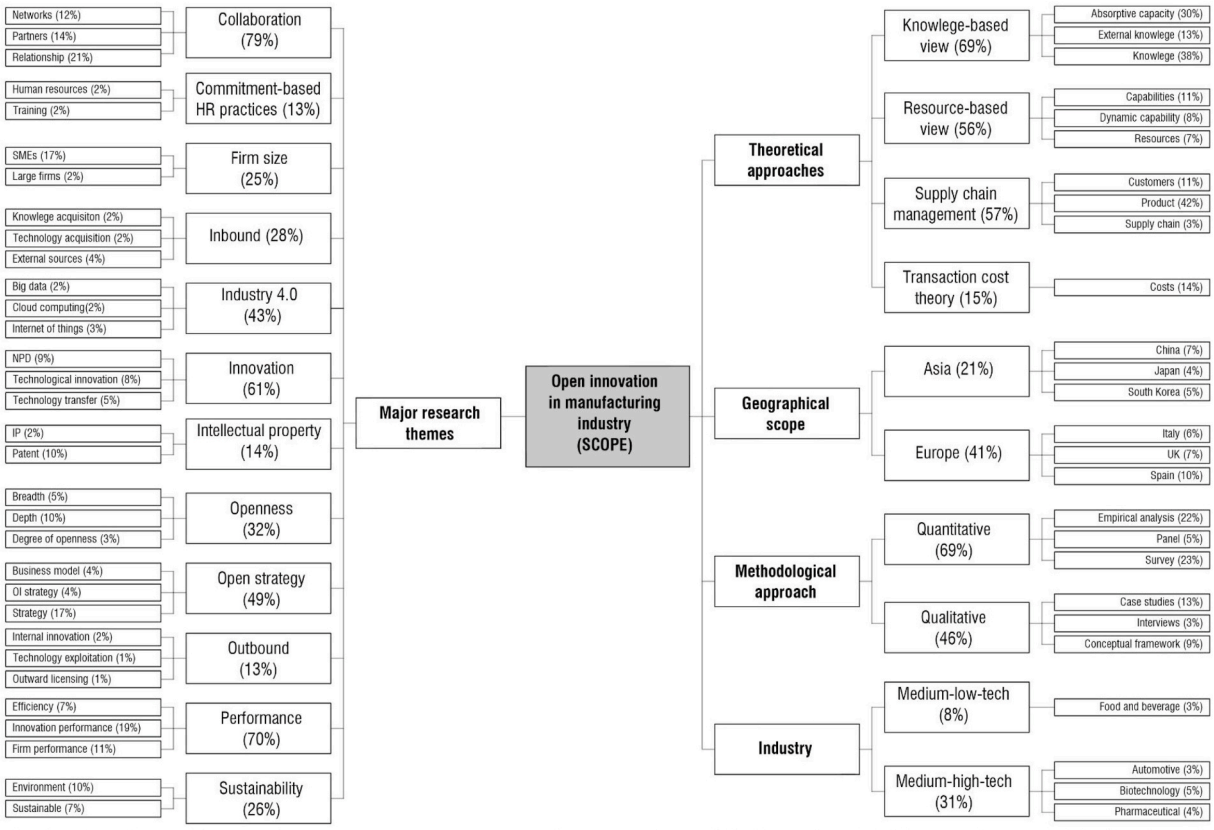

Fig. 5. The most used descriptors and their frequencies.

higher levels of innovative performance (Laursen and Salter, 2006). Triguero et al. (2019) established that the absorptive capacity of external knowledge can positively affect innovative performance.

The knowledge-based view is an extension of the resource-based view. It proposes that a firm's main motivation to collaborate with external associates is to allow them to profit from new technologies (Ahuja, 2000).

4.1.3. Resource-based view

Wernerfelt (1984) presented a resource-based view that honours organization-specific resources as a competitive advantage of an organization. The resource-based view and its extension, the capability-based view, both facilitate an understanding of the phenomenon of OI in manufacturing, especially in terms of dynamic capability (Kashan et al., 2018). Firms' capabilities strongly influence innovation. Teece et al. (1997, p. 516) described the notion of dynamic capabilities as *"the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments"*. It is important for the organization to believe in an open approach and to open up their boundaries. In other words, they must start thinking about developing dynamic capabilities that can support competitive new strategies, for example OI procedure claims (Grimaldi et al., 2013).

4.1.4. Supply chain management

In traditional explanations of supply chain management, the manufacturer is placed between the suppliers and the customers. However, in terms of OI, collaboration with suppliers or customers can become crucial for business. With regards to the OI paradigm, the authors investigated the methods by which companies integrate external information into new product development (NPD) (Wimalachandra et al., 2014; Bahemia et al., 2017). Vahter et al. (2014) discovered that small manufacturing plants invest more in relationships within the supply chain than larger plants. Jimenez-Jimenez et al. (2019) have explored this topic in terms of supply chain collaboration, while van Blokland et al. (2012) investigated the specific value chain of an aerospace company.

4.1.5. Transaction cost economics theory

Transaction cost economics theory suggests *"that the organization of economic activities is driven by the minimization of both production and transaction costs"* (Berchicci, 2013, p. 118). A company can expand their knowledge, but this is not without costs. Transaction cost economics has a significant impact on OI, although the connection is frequently implicit (Remneland-Wikhamn and Knights, 2012). Not all R&D activities are firm-centric and so it is more efficient for firms to outsource or combine their R&D activities with other firms.

Most of the studies used more than one theoretical approach when exploring OI practices in the manufacturing industry. Resource-based views and knowledge-based views are connected and are often used together. In the supplementary material, Table 7 shows the top five cited articles per year. These articles provide insight into authors, journals, contributions, and the most frequently used theories.

4.2. Major research themes

This research aims to contribute to existing literature on OI initiatives in the manufacturing industry. The results presented in Fig. 3 outline numerous approaches categorized as: collaboration (Kobarg et al., 2019; Lichtenthaler, 2013), commitment-based human resource practices (Lattorre-Navarro et al., 2016), firm size (Cruz-Cázares et al., 2013; Fu et al., 2014), inbound OI (Bianchi et al., 2016; Lakemond et al., 2016), Industry 4.0 (Nellippallil et al., 2019; Rocha et al., 2019), innovation (Chesbrough, 2003; Love et al., 2014), intellectual property (Cammarano et al., 2017; Ren and Su, 2015), open strategy (Barge-Gil,

2013; Gama, 2018), openness (Laursen and Salter, 2006; Vahter et al., 2014), outbound OI (Huang et al., 2013; Greco et al., 2018), performance (Kobarg et al., 2019; Park and Kwon, 2018), and sustainability (Prause, 2015; Shim and Park, 2016).

4.2.1. Collaboration

Collaboration is at the very centre of the OI paradigm. Essentially, if firms want to innovate then they have to collaborate with others as it is not possible for all relevant knowledge to exist within one firm. Our findings show that more than 79% of articles contain the keyword 'collaboration'. Firms can collaborate with different sources; for example, with customers, universities, consultants, or even competitors. Ozdemir et al. (2017) analysed new horizontal product alliances with competitors and new vertical product alliances with suppliers and research institutions. Lee et al. (2010) discovered that SMEs are better in inventions than as resources for commercialization, suggesting that SMEs should collaborate with other companies during the commercialization stage. Collaboration, innovation, and open strategy are very close to each other on the map (see Fig. 3). Collaboration is rarely investigated alone, but rather in terms of the ways in which it affects the firm's degree of openness and/or performance.

4.2.2. Openness and open strategy

One of the more notable publications in this field is a study conducted by Laursen and Salter (2006). These researchers investigated the connection between a firm's openness and its innovative performance. They introduced two new variables: breadth, as sources of knowledge or links to innovation (for example, suppliers, competitors, consultants, environmental standards, private research institutes, etc.) and depth, as the intensity to which these sources of knowledge were used. Love et al. (2014) have explored the impact of openness on learning effects, while Vahter et al. (2014) have discovered that the breadth of openness in innovation performance is more powerful for smaller manufacturing plants than for larger ones.

Barge-Gil (2010) studied Spanish firms and found that closed and semi-open strategies are the most recurrent. Three years later (2013), the same author discovered that, in comparison to semi-open innovators, open innovators are not as R&D intensive, but they are more R&D intensive than closed innovators. Xia (2013) analysed the connection between absorptive capacity and openness. It was found that exploratory openness depended more on the R&D elements of a company's prospective absorptive capacity. On the other hand, exploitative openness depended more on a firm's realized absorptive capacity.

4.2.3. Performance

Most articles showed the influence of degrees of openness on external knowledge of innovation performance (18.83%), but some articles deal with a firm's general performance (11.3%) and its financial performance (3.77%). Cruz-Gonzalez et al. (2015) approached this topic using the two open search strategies (breadth and depth) and explored their influence on a firm's performance.

Lazzarotti et al. (2010, p. 12) outlined the effect of openness on innovative performance. These authors depicted the degree of openness as: *"the number and type of partners and the number and type of phases of the innovation process open to external collaborations"*. Furthermore, they divided their variables into four types of OI models: open and closed innovators, integrated collaborators, and specialized collaborators. Ultimately, their findings revealed that integrated and specialized collaborators act as intermediators. Andries and Faems (2013) studied the influence of patenting activities on the financial performance of SMEs and large firms. They found that outward licensing activities would not produce short term financial benefits and that patenting activities would not cause cost disadvantages. The descriptor 'performance' is between inbound and outbound OI actions.

4.2.4. Inbound and outbound activities

OI includes both inbound (outside-in) and outbound (inside-out) activities. West and Bogers (2014) concluded that inbound OI has been more thoroughly explored than outbound, and the authors of this article have come to the same conclusion.

Inbound OI activities - or "the purposive inflows" (Chesbrough, 2003) - allow firms to acquire new knowledge, new ideas, and new technologies from outside of the firm. This includes *"customer involvement, external networking, external participation, outsourcing R&D, and the inward licensing of intellectual property"* (van de Vrande et al., 2009, p. 425). Terms such as 'outside-in' and 'technological exploration' are also used.

On the other hand, technological exploitation implies that firms can profit from their internal knowledge by using their internal innovations. The most frequently used method of commercializing ideas is venturing outwards towards the *"licensing of intellectual property or the involvement of non-R&D workers"* (van de Vrande et al., 2009, p. 424). Technological exploitation can also be referred to as outbound OI. In existing scholarly literature, the term 'inside-out' OI is also used. All terms retain the same meaning: "the use of purposive outflows of knowledge" (Chesbrough, 2003).

Hung and Chou (2013) studied the effects of technological exploitation and exploration on a firm's performance, while Pedrosa et al. (2013) explored its association with a different set of managerial appearances and practices in OI. Many articles deal with user involvement. For example, Leber et al. (2018) sought to establish whether or not customers could contribute to product development, specifically, with regard to refrigerator door handles. Tipu (2012) concluded that inbound OI activities were common, while outbound innovation activities were not as frequently used.

Inbound activities have been more thoroughly explored than outbound activities. We thus recommend that other researchers explore more outbound activities and more ways of commercializing ideas. Inbound and outbound activities are far from both qualitative and quantitative methodological approaches. As such, future research should focus on outbound OI, as many firms can profit from their own internal knowledge and it is therefore important to share good practices in order to allow for the expansion of the market. It is also vital that firms encourage their non-R&D employees to share their ideas and innovate.

4.2.5. Commitment-based human resource practices

High commitment human resource (HR) practices result in trust, long-term employment relationships, and employment security (Lattorre-Navarro et al., 2016). These should contribute to the formation of an innovation climate (Popa et al., 2017).

Ceylan (2013) found that commitment-based human resources (HR) affect the innovation performance of the firm indirectly. She concluded that commitment-based HR practices mainly affect organizational innovation activities, which increase innovation performance. McClean and Collins (2011) explore the connection between high-commitment HR practices and firm performance. They discovered that companies are willing to build HR practices for employees that clearly produce competitive advantages for the firm. Furthermore, HR practices can affect innovation activities by creating a culture of innovation and creativity (Brockbank, 1999). The descriptor 'Commitment based HR practices' is very close to the descriptor 'openness'. When a firm chooses to open up its innovation practice, there are radical changes for employees. Managerial staff within the firm have the difficult task of bringing about new cultures and new ways of thinking (Barham et al., 2020).

4.2.6. Firm size

There are many articles related to OI in research on SMEs (van de Vrande et al., 2009; Theyel, 2013; Verbano et al., 2015) which argue that they fill the gap(s) in scholarly literature as most studies pertain to large companies, in which the concept of OI was first initiated (Lee et al.,

2010). Chesbrough's theory was based on large American firms (Xerox, IBM, Intel), but OI is applicable to all industries and all enterprises (Gassmann et al., 2010).

Although OI began in large firms, only 2% of articles deal with this topic. The reason for this is that many authors have sought to fill the gap identified following the first publication in the field, and so our findings show that 18% of articles deal with OI in SMEs. Most researchers focus on one firm type - either SMEs or large firms. Crema et al. (2014) analysed company strategies, OI, and innovation performance through surveys based on SMEs in Italy. Some authors have analysed the difference between SMEs and large firms. For example, Jang et al. (2017) created an OI model for the complementary cooperation between SMEs and large firms in the manufacturing industry. Andries and Faems (2013) investigated the readiness of SMEs and large firms to participate in patenting. On the map, we can see that a firm's size is distanced from theoretical and methodological approaches and it can thus be considered a potential avenue for future research.

4.2.7. Industry 4.0

The term 'Industry 4.0' was presented by the German government as a strategic plan for their manufacturing industry, but other countries have also paid attention to digital transformation. In China, this period is referred to as *"Made in China (2025)"*; in the USA, *"Advanced Manufacturing Program"*; in the UK, *"4IR"*; and, in Japan, *"Industrial Value Chain Initiative"*. All terms refer to the fourth industrial revolution. There is a significant focus on transformation within the manufacturing industry. Technological innovation, regulatory changes, and turbulent global environments force firms towards new innovations and business models (Cooper, 2017). Although most research has focused on technological perspectives, Burmeister et al. (2016) discussed business models for Industry 4.0. and Industry 4.0's influence on the entire supply chain, embracing many OI approaches (Prause, 2015). In this line, Lardo et al. (2020) studied the ways in which capability providers can influence the transformation of the sustainable Industry 4.0. business model. Their findings show that many studied cases implemented OI in order to collaborate with different partners. This practice was identified as a foundation for value co-creation. Crupi et al. (2020) concluded that Italian digital innovation hubs practice OI by acting as knowledge brokers and knowledge sources, boosting the digital transformation of SMEs.

Overall, findings of empirical studies show that the descriptor Industry 4.0 is near medium-high technology manufacturing in Asia, which is not surprising seeing as China and South Korea are known for their digitization in manufacturing as well as their intelligent manufacturing. Industry 4.0 is distanced from the research themes of performance, human resource, and intellectual property, which is why it should be considered one of the most important topics for future research.

4.2.8. Innovation

Innovation is mostly explored in terms of 'innovation processes'. On the map, it is surrounded by descriptors such as 'open strategy' and 'collaboration', and by theoretical approaches, knowledge, and resource-based views. Kashan et al. (2018) observe the governance view as an element of the OI process, but innovation is not very close to a governance view. Aspects of the OI process are linked to a firm's evolution from closed innovation to OI. Gassmann and Enkel (2004) acknowledged three essential OI processes, based on their own empirical database of 124 companies: (1) The outside-in process, wherein buyers, suppliers, and external knowledge can affect innovations in companies; (2) The inside-out process, wherein the company can sell ideas, knowledge, and technology outside of the company; and (3) The coupled process, which is the connection between outside-in and inside-out processes, wherein the firm both gives and takes information.

4.2.9. Intellectual property

Collaboration with other partners is at the core of the OI paradigm. Firms have a hard time considering whether it is worth sharing knowledge with others or not. This is why intellectual property (IP), as well as intellectual property rights (IPR), are important research themes. Stefan and Bengtsson (2016) investigate the effects of IP protection mechanisms and openness on innovation performance. The connection between IP protection and OI is distinguished through a paradox (Brem et al., 2017). Firms should consider protection before sharing their knowledge with partners, however the procedure of protecting an idea can be expensive and time consuming. Vanhaverbeke (2006) found that companies could profit from the selective use of its IP by other companies with different models.

> *"Innovation activities measured by patenting are positively correlated with firm performance"* (Kazuyuki, 2016, p. 13). Ren and Su (2015) concluded how OI and IP protection both play a key role in the catch-up processes of two late-comer pharmaceutical firms. Andries and Faems (2013) explored the differences in patenting activities amongst large firms and SMEs and realized that patenting activities increased the ability of both to license out knowledge, but that the effect was more evident for larger firms. The role of intellectual property is very important in protecting innovation and around 7% of papers deal with this topic. However, there is still room for investigation, especially from a quantitative methodological approach.
>
> *"Small and large firms have different resources and capabilities and can benefit from patenting activities in different ways"* (Andries and Faems, 2013, p. 1089). Future research should focus on the different patenting activities of different sized firms.

4.2.10. Sustainability

This topic stems from OI perspectives, specifically in the manufacturing industry, and it includes all types of sustainability: economic, social, and ecological. One quarter of articles dealt with this topic. Sustainability is often explored through the lens of the 4th industrial revolution, with special attention dedicated to production scheduling (Shim and Park, 2016; Shim et al., 2017). Shim et al. (2017) proposed an algorithm which showed improved performance in production scheduling, and this was used in real manufacturing systems. For cost reductions and better efficiency, production scheduling uses big data, the internet of things, cloud computing, and cyber-physical systems. Yun and Liu (2019) suggested the use of a conceptual framework in order to explain OI using a quadruple-helix model. Kortmann and Piller (2016) developed a framework for the sustainability of business models in manufacturing firms, which is important across all value chains. In terms of OI, manufacturing firms are able to collaborate with domestic suppliers and, in this way, can cut transactional costs. They can also collaborate with customers and explore the ways in which clients perceive NPD processes (Leber et al., 2018). To understand sustainable supply chain management, it is important to explore all activities inside the supply-chain: designing, planning, execution, controlling, and monitoring. It is worth noting that this topic has become very popular in recent years and, with this in mind, future research suggestions have been made in the next section.

4.3. Geographical scope

The most frequent countries shown, in terms of their geographical scope, are in Europe (Costa et al., 2016; Cruz-Cázares et al., 2018) and Asia (Ren and Su, 2015; Fu et al., 2014). Only three articles concerning the topic have emerged from Africa (Simiyu et al., 2010), and two from South America (Rocha et al., 2019) and Oceania (Teng et al., 2014), respectively. In the last section of the article, researchers are encouraged to explore OI practices in manufacturing firms on other continents.

Europe is characterised by articles dealing with openness and performance, while Asia frequently examines close to medium-high tech and Industry 4.0.

4.4. Methodological approaches

The quantitative method is most frequently represented in terms of methodological issues. A lot of data was collected concerning Community Innovation Surveys (CIS) (Barge-Gil, 2010; Silva et al., 2008), which are surveys implemented by national statistical offices throughout the European Union and in Norway and Iceland. Qualitative studies were mostly case-based (Guo and Zheng, 2019; Kashan et al., 2018) and qualitative research was situated between supply chain management and collaboration. Quantitative research is linked to knowledge-based views and is very close to open strategy and innovation. Intellectual property, firm size, sustainability, and commitment-based HR practices were major research themes located far from both qualitative and quantitative methods, thus offering a potential avenue for future research.

4.5. Industry

In spite of the fact that OI initially emerged in the high-tech sector, there has been an increase in articles exploring the innovation processes of the low-tech sector (Gassmann et al., 2010). The most researched industry in the low-tech sector is the food industry. Low-tech firms can develop knowledge connected to non-R&D activities, indirectly developing new products (Kastelli et al., 2018).

Based on the Statistical Classification of Economic Activities in the European Community (NACE), the industry is organized by technological intensity: low-tech, medium-low-tech, medium-high-tech, and high-technology manufacturing industries (see Table 8, available in the supplementary material). For better transparency, low-tech and medium-low-tech industries are connected and shown together on the map. The same was done for high-tech and medium-high-tech. The authors found that descriptors representing the medium-low-tech classification of the manufacturing industry was very distant for both qualitative and quantitative methods.

5. Future research

The synthesis of up-to-date literature, performed by means of content analysis combined with HOMALS statistical procedure, allows us to outline key insights and provide a roadmap for the future development of OI in the research field of manufacturing. Given that studies to date have predominantly focused on collaboration, open strategy, breadth and depth, and innovation from the firm's perspective, topics such as sustainability, human resources, and Industry 4.0 require further attention.

5.1. Sustainability

In regular supply chain management, the manufacturer exists between suppliers and customers but, in terms of OI, collaboration with suppliers or customers can prove to be crucial for business. With the help of external knowledge, a firm can improve its sustainable innovation and positively influence organizational sustainability (Lopes et al., 2017).

By optimizing their processes through the whole supply chain, manufacturing firms can minimize waste and make production more sustainable. Additionally, products marked as sustainable tend to generate more profit than those marked as non-sustainable (Whelan and Kronthal-Sacco 2019). With this in mind, the resource-based view could assist manufacturing firms in creating and modifying their dynamic capabilities by simultaneously improving their economic, environmental, and social sustainability. Furthermore, manufacturers have the potential to modify their sustainable supply chains through collaboration. With the help of external partners, manufacturers could increase their income whilst using natural resources and ensuring better conditions for their workers. Although the EU has created a strategy for implementing the UN's 2030 Agenda for Sustainable Development, there is still a gap in research when it comes to sustainable activities through OI in the manufacturing industry in Europe (UN General Assembly, 2015). To fill these gaps, future research should focus on the resource-based view, low-tech industries, and Europe as a geographical scope as initiators of sustainability for OI in the manufacturing industry.

5.1.1. Resource-based view

The resource-based view highlights the importance of a firm's resources and capabilities. In the context of OI, firms continue to develop their resources, sharing them with partners and adapting them in order to become more competitive. The results of this analysis show the lack of study into sustainability in terms of the resource-based view (see Fig. 3). It would be useful to explore how the resource-based view enhances sustainability in the long run, seeing as firms' resources are sources of competitive advantage and are often the reason behind firm's higher profit and/or better market position. In today's fast-changing environment, in which customers value personalized products, production has a great impact on the environment and society. Future research should thus focus on firms' dynamic capabilities and the ways in which the combination of internal and external competencies can be built and modified in order to make production more sustainable.

5.1.2. Low-tech industries

High-tech and medium-high tech manufacturing are much more connected to OI research than low and medium-low manufacturing (more than 30% of articles dealt with medium-high tech, and only 8% with medium-low tech). Thus, scholars are encouraged to explore the ways in which low-tech manufacturing industries - as OI strategies - are operational and effective in making internal research and development efforts more successful in both high and low-tech sectors (Santamaria et al., 2010). According to the results depicted in Fig. 3, we can conclude that the intersection of sustainability and medium-low-tech industries represent a research opportunity. Future research should focus on the influence of open sustainability innovation on the food and beverage industry in order to see how low-tech industries can reduce their costs and improve their time to market.

5.1.3. New combinations of industries

To date, scholars have payed particular attention to role of OI in industries such as the automotive industry (Schuster and Brem, 2015; Ciravegna et al., 2013; Homfeldt et al., 2019), the chemical industry (Bieringer et al., 2013), the pharmaceutical industry (Dahiyat, 2015; Gambardella and Panico, 2014), the bio-pharmaceutical industry (Cammarano et al., 2017; Xia and Roper, 2016), and the food and beverage industry (Triguero and Fernandez, 2018; Costa et al., 2016; Miglietta et al., 2017). Scholars are therefore encouraged to investigate OI in other specific industries, as well as in new combinations of industries, for example biotechnology and pharma (Bogers et al., 2017). It would be useful to explore how the collaboration between biotechnology and the food and beverage industry influences sustainability. The food and beverage production industry are one of the largest in the world and it is important to minimize waste and expand the use of a renewable energies. According to The Intergovernmental Panel on Climate Change report (2020), around 21 to 37 per cent of the world's greenhouse gas is linked with our food systems.

5.1.4. Geographical scope

Furthermore, the results of the analysis indicate that OI in manufacturing has predominantly focused on firms in Europe, which could be partially explained by the data availability obtained through the Community Innovation Survey (CIS) (Lichtenthaler, 2013; Greco

et al., 2017); as shown, for example, in relation to Italy (Lerro et al., 2016; Bonfanti et al., 2018), and the UK (Mina et al., 2014; Audretsch and Belitski, 2019). The second most frequent geographical area was Asia, for example, South Korea (Park and Kwon, 2018; Yun et al., 2018) and China (Huang et al., 2018; Guo et al., 2016).

Future research could bring to light the approaches and strategies of manufacturing firms in Oceania, South America, and Africa. As numerous manufacturing firms are located in Australia, future research could also investigate OI practices in, for example, Preshafood Limited – a food and beverage company from Melbourne - or Gecko Gear, which specializes in iPod, iPad, and iPhone accessories. Researchers could investigate the differences in OI practices between their warehouses in Australia and China. South America also offers a lot of potential in terms of the exploration of specific industries, such as OI in aircraft firms (of which there are many), such as Aero Bravo, Paradise Aircraft Advanced Composites Solutions, or Companhia Aeronàutica Paulista.

Although Europe is the most frequently researched geographical region in terms of OI in the manufacturing industry, it is still very far from achieving sustainability (see Fig. 3). Future research should therefore focus on collaborations between developed and developing countries. For example, how can the exchange of knowledge create a greater value for both countries? Or, how could OI enhance frugal innovation?

To summarize, future studies could aim to answer:

RQ1: How can dynamic capabilities encourage more sustainable production?

RQ2: How can open sustainability innovation reduce costs and improve time to market in the food and beverage industry?

RQ3: How might the collaboration between biotechnology and the food and beverage industry reduce production waste and increase the use of renewable energies?

RQ4: How might collaboration between Western companies and companies based in Africa influence social sustainability?

5.2. Commitment-based HR practices

Results show that only 13% of articles dealt with the topic of commitment-based HR practices in terms of OI in the manufacturing industry. Articles were more focused on technologies and processes of digitalization with respect to the fourth industrial revolution than on leadership and how these changes have influenced the culture of the company.

In 2020, where the whole world is affected by the COVID-19 pandemic, it is necessary for managers to have proper skills with which to motivate their team members. With this in mind, it is more important than ever to study virtual teams, training and development, skill management, change management, and other human resource practices affecting inbound and outbound firm activities, while simultaneously influencing NPD performance. The knowledge-based view, as a theory that advocates knowledge as a firm's competitive advantage, can also be a valuable approach in clarifying the ways in which knowledge can be transferred among both team members and partners in a supply chain.

5.2.1. Knowledge-based view

With new innovations and technologies, it is important to adapt new business models and cultures. Sometimes, employees do not feel comfortable when collaborating with external sources. "Not invented here" syndrome is very common in the context of OI. Van de Vrande (2009) proposes that future research should work on linking OI to HR management, as OI generates HR management problems. Markovic et al. (2020) highlighted that the training and deployment of teams are the "softer" drivers of outside-in OI.

A definitive lack of HR research, in accordance with the knowledge-based view (see Fig. 3), was observed in this study. Knowledge as an intangible capability constitutes the competitive advantage of a firm. It would be valuable for future studies to explore how knowledge transfer among both team members and partners (suppliers and customers) can influence inbound and outbound OI activities in order to improve NPD performance. Further research into HR management, specifically top management, teamwork, recruiting, and talent management, is necessary.

5.2.2. Implementation of the digital manufacturing

Industry 4.0 has shortened product life cycles and it is thus more important than ever for firms to collaborate with external partners (Mubarak and Petraite, 2020). Additive manufacturing influences the processes of creating substances by enabling manufacturing companies to create prototypes much more quickly. New technologies thus allow manufacturing firms to test more innovations and place new products on the market more rapidly.

The fourth industrial revolution represents the new digital age, with the focus on advanced technology. Future research should emphasize human resource practices in terms of formal aspects (e.g. strategy or communication) and informal (e.g. trust) and explore how they can strengthen the connection between OI and NPD performance. The World Economic Forum (2020) has identified the top required skills for managers in the future. It would be useful to study how complex problem solving, critical thinking, creativity, and/or people management can influence inbound and outbound OI activities. These new skill requirements were obtained under the influence of globalization, digitalization, and COVID-19.

5.2.3. Qualitative approach

A large amount of research has been conducted through quantitative approaches (i.e. findings show that 69% of authors use quantitative methods), especially with regards to the Community Innovation Surveys (CIS). In order to contribute to the paradigm, more qualitative and mixed methods should be relied upon. Researchers should fill this gap by seeking to develop an in-depth understanding of human behaviour, for example, by interviewing top managers to see how they have adopted OI practices in the manufacturing industry, or by asking employees to explore how external ideas and collaborations have affected their firm's culture.

In summary, the future studies should address:

RQ1: How can the knowledge transfer processes between a team and partners improve NPD performance, using inbound and outbound open innovation activities as mediators?

RQ2: How can digital trust moderate the relationship between open innovation and NPD performance?

RQ3: How can the new required managerial skills (e.g. complex problem solving, critical thinking, and people management) influence collaboration across the whole supply chain?

RQ4: What is the role of HR management in creating the open innovation strategy in manufacturing?

5.3. Industry 4.0

Industry 4.0 has been considered a trending topic for academics and practitioners (Marzi et al., 2017). It represents the fourth industrial revolution and will affect various industries: manufacturing, finance, the food industry, the cleaning industry, and many others. For the successful adoption of Industry 4.0, it is very important for firms to implement vertical and horizontal integration. The connections between OI and Industry 4.0 lie in innovation and collaboration between all partners in the production process.

The fourth industrial revolution has changed manufacturing firms' business models and this can influence performance in the long run. Firstly, companies need to invest in new technologies and make substantial efforts when reorganizing their business. In the long run, they could increase their profit, reduce costs, and position themselves as a market leader. Although companies need to collaborate with external parties in order to optimize their capabilities, they also need to be careful and protect their most valuable resources.

5.3.1. NPD performance

Researchers are encouraged to investigate the role of advanced manufacturing technologies - for example, additive manufacturing - with specific focus on the ways in which these technologies could be implemented in digitalized manufacturing systems. Additive manufacturing plays an important role in industries such as aerospace, aircraft, the biomedical industry, and the pharmaceutical industry. It would be useful to explore how the implementation of additive manufacturing might boost outbound OI activities and improve NPD performance.

5.3.2. Intellectual property

The fourth industrial revolution has changed the way in which we protect innovations. In line with Industry 4.0, the focus is on the protection of intangible things, such as data and virtual systems. Companies open themselves up to risk when increasing their degree of openness and sharing their knowledge and technology with others. However, it can be useful for a firm to collaborate with their competitors, customers, or suppliers. There is a thin line between openness and protection and, as such, every business should create their own IP strategy according to their business models. In summary, the following RQs for future research are suggested:

RQ1: How can the implementation of additive manufacturing encourage outbound open innovation activities and, consequently, improve NPD performance?

RQ2: How can Industry 4.0 solutions open up new potential for collaboration in the pharmaceutical industry?

RQ3: How does open innovation mediate the relationship between digital revolution and intellectual property rights?

RQ4: What kind of digital patents are the most beneficial when protecting digital business models in the manufacturing industry?

6. Conclusions

In this increasingly dynamic business environment, it is important for manufacturing firms to open up their boundaries and exchange technology and knowledge with other external partners. Therefore, the OI paradigm is suitable for both researchers and practitioners as it offers a way by which innovation can be thought of as an open system that affects every continent and every industry.

6.1. Practical and social contributions

There are many companies that switched their closed business models and started to cooperate with other stakeholders, accomplishing results such as: new products, better performance, or more sustainable business (P&G, GE, Samsung, Lego, NASA). In this vein, researchers are encouraged to collaborate with practitioners to explore, for example, how top managers adopt OI practices (Yuan et al., 2009), and how they can buffer "not invented here" syndrome (van de Vrande, 2009). Additionally, managers and researchers from developed countries are encouraged to collaborate with developing countries, as there are indications that OI can boost frugal innovations (Hossain, 2013; Dandonoli, 2013). Hence, the collaboration between developed and developing companies could contribute to a more sustainable environment (Dandonoli, 2013). In short, empirical studies have noted that higher degrees of openness to external knowledge improves firms' performance in the manufacturing industry (Berchicci, 2013; Cruz-Gonzalez et al., 2015; Greco et al., 2018; Wang et al., 2012).

6.2. Theoretical implications

This systematic literature review extends former literature reviews such as those pertaining to OI in SMEs (Hossain and Kauranen, 2016; Torchia and Calabro, 2019), OI models (Lazzarotti et al., 2010), and negotiations in OI (Barchi and Greco, 2018), by examining OI in the manufacturing industry without any time constraints. This study sought to compile and categorize the application of OI in the manufacturing industry context by answering the following RQs:

RQ1: What are the underlying theoretical approaches, major research themes, geographical scopes, methodological approaches, and industries in open innovation in the manufacturing research field?

RQ2: What future research streams exist in open innovation research in a manufacturing context, in terms of theoretical and practical approaches?

With regards to the first research question (RQ1), the literature review synthesized five theories which best describe the OI paradigm in a manufacturing industry context. The most frequently used theories are the knowledge-based view, supply chain management, and the resource-based view, while transaction cost economics theory and the institutional theory are the least studied theories. The results show that resource-based and knowledge-based views are often studied together, along with topics such as open strategy, innovation, and collaboration.

With regards to the second research question (RQ2), future research guidelines were based on the outcome of the authors' in-depth study of reviewed papers, combined with the results of the HOMALS statistical approach. This paper highlighted the opportunity for the resource-based view to be studied as a theory that could influence manufacturing firms' sustainable strategies. Through the adjustment of their dynamic capabilities, manufacturing firms could accomplish more sustainable production. On the other hand, the knowledge-based view has been recognized as a potential way of studying the manufacturing industry's "soft side". During the COVID-19 pandemic, it is more important than ever to study managers' skills, teamwork, change management, and the ways in which knowledge transfer between team members and partners can influence OI activities and improve NPD performance.

The literature review confirms the diversity of the theoretical approaches and major research themes used to define the OI paradigm in the manufacturing industry. This review contributes to the creation of current and future knowledge by amplifying the methodology.

6.3. Limitations

The scope of OI is very wide and the manufacturing and service industries are very different, meaning that they should, therefore, be explored separately. We therefore suggest that other authors explore the adoption of OI in the service industry and look at, for example, how the implementation of OI in the service sector changes business models through knowledge exchange.

Only articles and reviews were selected for this analysis, while books and conference proceedings were left out. Furthermore, some of the most prolific languages were excluded, as only articles and reviews in English were applicable. These omissions could offer interesting avenues for future research.

To identify the current state and the future research directions of OI in the manufacturing industry, this paper used a hybrid review method: the outcome of the authors' in-depth analysis of the reviewed papers was

combined with the results of the HOMALS statistical approach. Thus, future researchers are encouraged to study OI in the manufacturing industry from a different methodological perspective. Our results show that there are many papers using the quantitative approach when studying OI in the manufacturing industry. Therefore, further meta-analytical reviews studying the connections between variables in OI in the manufacturing industry will be valuable.

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Appendix A. Supplementary data

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