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THE CONFLUENCE OF I.4.0 TECHNOLOGIES AND NEW BUSINESS MODELS: A SYSTEMATIC LITERATURE REVIEW

A CONFLUÊNCIA DAS TECNOLOGIAS I.4.0 E NOVOS MODELOS DE NEGÓCIO: UMA REVISÃO SISTEMÁTICA DE LITERATURA

LA CONFLUENCIA DE LAS TECNOLOGÍAS I4.0 Y NUEVOS MODELOS DE NEGOCIO: UNA REVISIÓN SISTEMÁTICA DE LA LITERATURA

Josélia Elvira Teixeira[1]
Ana Teresa Tavares-Lehmann[2]

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Abstract

Objective of the study: The study's objective is to provide a systematic literature review on the coevolution of the Technologies associated to Industry 4.0 and business models.

Methodology/approach: The research was built on conceptual blocs at the interface between Industry 4.0 (I 4.0), business models (BM) and digitalization /digital business models (DBM) in order to identify relevant trends. Through bibliometric techniques, 80 articles were selected from Scopus and WoS, using specialized software.

Originality/ Relevance: Few studies exist on the interface under analysis. This article contributes to this emerging literature, providing a synthesis of such literature, including both a detailed descriptive component and an analysis of the main thematic clusters associated to this interface.

Main results: The literature still needs to evolve into a framework of a 4.0 business model. The majority of the existing studies focus on business models to specific technologies associated to Industry 4.0. Among the 80 articles scrutinized, 56 were associated to business models and I4.0, and 24 linked business models and digitalization. Few really described a business model that could be characterized as an I4.0 business model.

Theoretical/methodological contributions: Identification of key studies underlying the elaboration of an innovative business model associated to I4.0. An immediate and useful characterization of the literature. Identification of the main thematic clusters.

Social/management contributions: To provide academics and professionals (especially in Business/Economics) with a detailed and thorough review of the most relevant literature, including the main aspects underlying the creation of innovative business models based on I4.0.

Keywords: Industry 4.0. Digital business model. Digital platform. Innovation. Competitiveness.

[1]Assistant Professor at Department of Economics (Universidade Estadual do Centro-Oeste-UNICENTRO), Phd in Public Policy (UFPR). Guarapuava – PR, Brazil. joseliateixeira@unicentro.br

[2]Associate Professor at Faculty of Economics and Management (Universidade do Porto), Phd in Economics (University of Reading), Porto – Portugal. atavares@fep.up.pt

Resumo

Objetivo do estudo: O estudo tem como objetivo apresentar a literatura sistematizada sobre a confluência dos modelos de negócios a partir das tecnologias associadas a Indústria 4.0.

Metodologia/abordagem: A pesquisa foi construída em blocos conceituais na interseção entre Indústria 4.0 (I4.0), modelos de negócios e digitalização para identificar tendências para um modelo de negócios I4.0. Por meio das técnicas de bibliometria, foram selecionados 80 artigos científicos da Scopus e WoS, utilizando software especializado.

Originalidade/relevância: Há poucos estudos sobre a interface estudada, e este artigo contribui para esta literatura emergente, proporcionando uma síntese da literatura, tanto numa componente descritiva detalhada, como da análise dos principais clusters temáticos associados.

Principais resultados: A literatura ainda está consolidando-se em relação a um framework nomeadamente dito modelo de negócios 4.0. A maioria dos trabalhos abordam modelos de negócios para específicas tecnologias associadas à Indústria 4.0. Dos 80 manuscritos analisados 56 estavam associados a modelos de negócios e Indústria 4.0, destes 24 manuscritos restringiam a investigação a modelos de negócio digitais e I4.0. Entre eles, poucos descreviam realmente um modelo de negócio I4.0.

Contribuições teóricas e metodológicas: Identificação dos principais trabalhos para a elaboração de um inovador modelo de negócios associado à I4.0. Fotografia imediata e útil do estado da arte da literatura. Identificação de principais clusters temáticos.

Contribuições sociais/ de gestão: Contribuir para os acadêmicos e profissionais da área (especialmente de Negócios/Economia) com o levantamento da literatura mais recente e relevante que perfila os principais elementos para a criação de inovadores modelos de negócios 4.0.

Palavras-chave: Indústria 4.0. Modelos de negócios digitais. Plataforma digital. Inovação. Competitividade.

Resumen

Objetivos del estudio: El estudio tiene como objetivo presentar la literatura sistemática sobre la confluencia de modelos de negocio de tecnologías asociadas a la Industria 4.0.

Metodología/abordaje: La investigación se construyó sobre bloques conceptuales en la intersección de Industria 4.0 (I4.0), modelos de negocio y digitalización para identificar tendencias hacia un modelo de negocio I4.0. Mediante técnicas bibliometricas, se seleccionaron 80 artículos científicos de Scopus y WoS, utilizando software especializado.

Originalidad/relevancia: Existen pocos estudios sobre la interfaz estudiada, y este artículo contribuye a esta literatura emergente, brindando una síntesis de la literatura, tanto en un componente descriptivo detallado como en el análisis de los principales clusters temáticos asociados.

Principales resultados: La literatura aún se está consolidando en relación con un marco denominado modelo de negocio 4.0. La mayoría de los artículos abordan modelos comerciales para tecnologías específicas asociadas con la Industria 4.0. De los 80 manuscritos analizados, 56 estaban asociados a modelos de negocio e Industria 4.0, de estos 24 manuscritos restringieron la investigación a modelos de negocio digitales e I4.0. Entre ellos, pocos realmente describieron un modelo de negocio I4.0.

Contribuciones teóricas/ metodológicas: Identificación de los principales trabajos para el desarrollo de un modelo de negocio innovador asociado a I4.0. Fotografía inmediata y útil del estado del arte de la literatura. Identificación de los principales clusters temáticos.

Contribuciones sociales / gerenciales: Contribuir a académicos y profesionales en el campo (especialmente en Negocios / Economía) con presentación de la literatura más reciente y relevante que describe los principales elementos para la creación de modelos de negocio innovadores 4.0.

Palabras-clave: Industria 4.0. Modelos de negocios digitales. Plataforma digital. Innovación. Competitividad.

1 Introduction

The term "Industry 4.0" was coined in Germany 2011, at the Hannover Messe leading worldwide event on industrial technologies (Ślusarczyk, 2018; Sung, 2018). Since then, it became widely accepted in the literature as a new stage in industrial development (Benitez, Ayala, & Frank, 2020). Indeed, this stage is even considered a "Fourth Industrial Revolution" (Schwab, 2016). It is supported by a wide array of innovative digital technologies, like Internet of Things (IoT), Cyber-physical systems (CPS) and Artificial Intelligence (AI) (Li, Dai, & Cui, 2020; Llopis-Albert, Rubio, & Valero, 2021). Such technologies allow for high connectivity and integration between the real/physical and the digital/virtual world, between intelligent/ smart objects (products) and machines (Fatorachian & Kazemi, 2018; Queiroz, Pereira, Telles, & Machado, 2019) interacting and supplying informations in real time with human resources (Safar, Sopko, Bednar, & Poklemba, 2018). Thus, the smart factory resulting from a I4.0 context promotes the autonomous control of processes, avoiding waste, reducing production costs, making production more flexible and adding greater value (Nascimento *et al.*, 2019).

The introduction of the I4.0 concept creates business opportunities, and innovative business models through the introduction of digital technologies (Hervas-Oliver, Gonzalez-Alcaide, Rojas-Alvarado, & Monto-Mompo, 2021) which may lead to the increase of competition in the local market as well as in the global market (Safar *et al.*, 2018). Meanwhile, it has been noted that manufacturing firms have used I4.0 technologies to improve their processes rather than to enable the adoption of a new and innovative business model, as they analyze their absorptive capacity in order to define their innovation strategy, and not always their strategy consists of launching a disruptive business model (Müller, Buliga, & Voigt, 2021). Although there is an increasing number of studies on Industry 4.0 and also about innovative business models in general, there is scarce literature specifically linking business models and Industry 4.0 (I4.0 BMs) (Weking, Stöcker, Kowalkiewicz, Böhm, & Krcmar, 2020) and on how digital transformation has impacted on such models (Frank, Mendes, Ayala, & Ghezzi, 2019). Agostini and Nosella (2021), in a recently published article after our bibliometric research was developed, analyze the interface between I4.0 and business models, corroborating the scarcity of studies specifically exploring that interface.

Digital transformation has promoted a host of changes on firm's strategies, on the way they produce and deliver goods and services, due to the application of the already mentioned digital technologies (Fernandez & Gallardo-Gallardo, 2021). Given this context and the

relevance and pertinence of the topic, this article aims to present a bibliometric review about I4.0 and the impact of digital transformation on business models.

2 Industry 4.0, digital transformation and business models

The term Industry 4.0 has been associated to other interchangeable designations such as "Fourth Industrial Revolution" or complementary expressions like "*Smart Manufacturing*" (Kerin & Pham, 2019; Kusiak, 2018), "*Smart Industry*", "*Intelligent Manufacturing*" (Weking *et al*., 2020) or "*Industrial Internet*"(Müller *et al.*, 2021), a term diffused by General Electric (Ślusarczyk, 2018). Beyond the increasing academic interest, the concept has been extended to different private and public *stakeholders* (Li *et al*., 2020). Governments have designed and implemented programs and policies in order to stimulate the deployment of I4.0 technologies, aiming to increase the competitive advantage of firms (Ślusarczyk, 2018).

For Kusiak (2018), the smart factory uses such CPS-related technologies to integrate on a daily basis the activities involved in the productive process, and to monitor such processes in real time. These mechanisms allow controlling through a software connecting computers, networks and physical processes (Kerin & Pham, 2019). Although manufacturers try to increase competitiveness via CPS, the full range of opportunities through which I4.0 technologies can support production is still a topic warranting study, in order for these technologies to fulfil their potential at that level (Nascimento *et al*., 2019).

The Internet of Things (IoT) materializes a network connecting computational systems with the physical world, allowing the interaction, for instance, of RFID sensors and *smartphones* between robots/machines and humans. Such integrated connections generate extremely large datasets that may be analyzed computationally to reveal patterns, trends and associations – in other words, *Big Data* (Gottge, Menzel, & Forslund, 2020). The main aim is to automatize decision-making (Nascimento *et al.*, 2019). Furthermore, cybersecurity is a key aspect for the functioning of the smart factory, given that digital transformation increases exposure to cyberattacks (Emer, Unterhofer, & Rauch, 2021; Kusiak, 2018).

For Teece (2010), the key factor in a business model is to define the way through which the company delivers value to its clients, influences the clients to pay that amount , and transforms those payments in profit. *Business Model*s – BMs are the representation of how the firm conducts its business, creates value for the stakeholders, and for itself (Bagnoli, Dal Mas, & Massaro, 2019). BM is a complex structure of firms to create, capture and deliver value. *Business Model Innovation* (BMI) comprises the change of traditional BM in order to capture

value creation (Mihardjo, Sasmoko, Alamsjah, & Elidjen, 2019). The clients' experience will be a critical factor for BMI success in this era of digital transformation (Bawono & Mihardjo, 2020).

According to Weking *et al.* (2020), the patterns of BMs represent recurring blocs of a BM in an abstract and general form and that may be derived from an innovative business model.

Digital platforms have been used by firms to connect a vast network of different resources to capture value, amplifying in that way new opportunities for the supply of advanced services. Several companies (like Apple, Microsoft and Amazon) adapted their platform-based BMs in order to increase their scale and experimented considerable and fast growth (Tian, Coreynen, Matthyssens, & Shen, 2021).

There is a strong association between digital innovations and I4.0 technologies in the smart factory. Firms are much more receptive to change their BMs towards an auto-adjustable model (Del Giudice *et al.*, 2021). The digital transformation of the products of the companies is one of the necessary industrial stages for the transition for an interconnected firm typical of I4.0 (Frank et al., 2019). That is, I4.0 promotes the digitalization of firms, and the necessary further step is to rethink and innovate at the BM level (Bagnoli et al., 2019; Mihardjo *et al.*, 2019). Industry 4.0 is not referring only to production, but to all the business cycles and to the overall process of value creation. In this perspective, the paper reviews systematically the available literature on the I4.0 – BM- DBM (Digital BM) interface.

3 Methodology

3.1 Definition of the research method

This section presents the key methods used to extract the references and to compose the research portfolio, the tools utilized for the bibliometric study and the systematic analysis which determined the main axes of research on the chosen theme.

Bibliometry is a methodology increasingly used in different areas of knowledge (Aria & Cuccurullo, 2017). The term 'bibliometry' has been coined by Pritchard and published in the *Journal of Documentation* in 1969 (Broadus, 1987). It includes studies that apply mathematical and statistical methods to bibliographic documents, aiming to quantify different patterns in the literature analyzed (Groos & Pritchard, 1969). The bibliometric analysis of a data base allows the inference of considerations about the scientific area under study through publications' sources, demographic aspects of publications and authors, number of citations, networks and scientific collaborations established (Ozdagoglu, Ozdagoglu, Topoyan, & Damar, 2020).

This study developed an analysis of the descriptive statistics of the bibliographic metadata, mapping of the networks and content analysis in order to provide, to the best of our knowledge, the most up-to-date literature review on Industry 4.0 and the digitalization of firms' business models, in order to understand the characteristics and the trajectories identified in the literature. The bibliometric study aims to answer the following questions:

Q1: What are the most relevant authors and publications, and their affiliations?

Q2: What are the main countries where such publications originate, and the annual evolution of publications about the theme?

Q3: What are the main research trends on the theme under analysis?

Q4: Is there a business model for Industry 4.0 associated with this literature?

3.2 Establishment of criteria for searching articles and selecting a database

In order to gather a significant dataset about relevant bibliography published on the theme, we used the Main Collection of Clarivate Analytics Web of Science (WoS) and SciVerse Scopus, both being prestigious, inclusive and commonly used bibliographic databases in different knowledge areas (De Carvalho *et al*., 2020).

Given that in the I4.0 literature often other similar terms are used (like "*smart manufacturing*", "*intelligent manufacturing*" and "*Fourth Industrial Revolution*" (Ślusarczyk, 2018) we used the Boolean term "OR" between such terms. We combined such key terms with other blocs of keywords structuring the research theme, notably "*business models*" and "*digital platforms*", deemed relevant for our research. In the bloc digital platforms, we considered the following keywords: digital platform; economic platform; e-commerce; and electronic commerce.

The search was limited by type of document – we only used articles and review articles (including those with anticipated access) in scientific journals, in order to guarantee access to peer, double-blind reviewed scientific articles. The documents were also limited to the wide area of Economics and Business. Given that WoS and Scopus have slightly different designations for the relevant areas, we considered in WoS the following sub-areas: Economics, Business, Finance and Management; while in Scopus we included the following sub-areas: Business, Management, Accounting, and Economics, Econometrics and Finance. Other criterion employed to limit the selection was language – we chose to include only articles in English, considering that it is the dominant language in scientific publications included in these

major data bases. The period of extraction was not limited, that is, we included all publications until the extraction date (May 31st – June 1st 2021).

After the search of the metadata contained in WoS and Scopus, extracted according to the above mentioned criteria, such metadata were exported to Excel files, resulting in N= 343 publications. These publications were organized according to: Authors, titles, sources, year, citations, abstract, language, document type, DOI and type of source. First, in the same Excel file, the documents duplicated in each search in WoS and Scopus were identified, leading to the exclusion of 67 duplicated documents, resulting in N=276. In another Excel file, we included all the results of all combinations of searches by different keywords, leading to the further elimination of 21 more duplicated publications – hence generating a total portfolio of N=255 documents. Table 1 presents the main results of the WoS and Scopus extractions, by combinations of keywords.

Table 1

Results of extractions

Keywords 1	Keywords 2	WoS		Scopus	Results by categories, document types and languages	Duplicates	Total without duplicates
("i4.0" OR "industry 4.0" OR "smart manufact*" OR "intelligent manufact*" OR "Fourth Industrial Revolution")	AND ("business model")	44		127	171	26	145
("i4.0" OR "industry 4.0" OR "smart manufact*" OR "intelligent manufact*" OR "Fourth Industrial Revolution")	AND ("Platform*" OR "Digital platform*" OR "Platform economy" OR "e-commerce" OR "Electronic commerce")	60		112	172	41	131
Total		104		239	**343**	67	**276**
(-) Duplicates							21
Database Total							**255**

Source: Own elaboration.

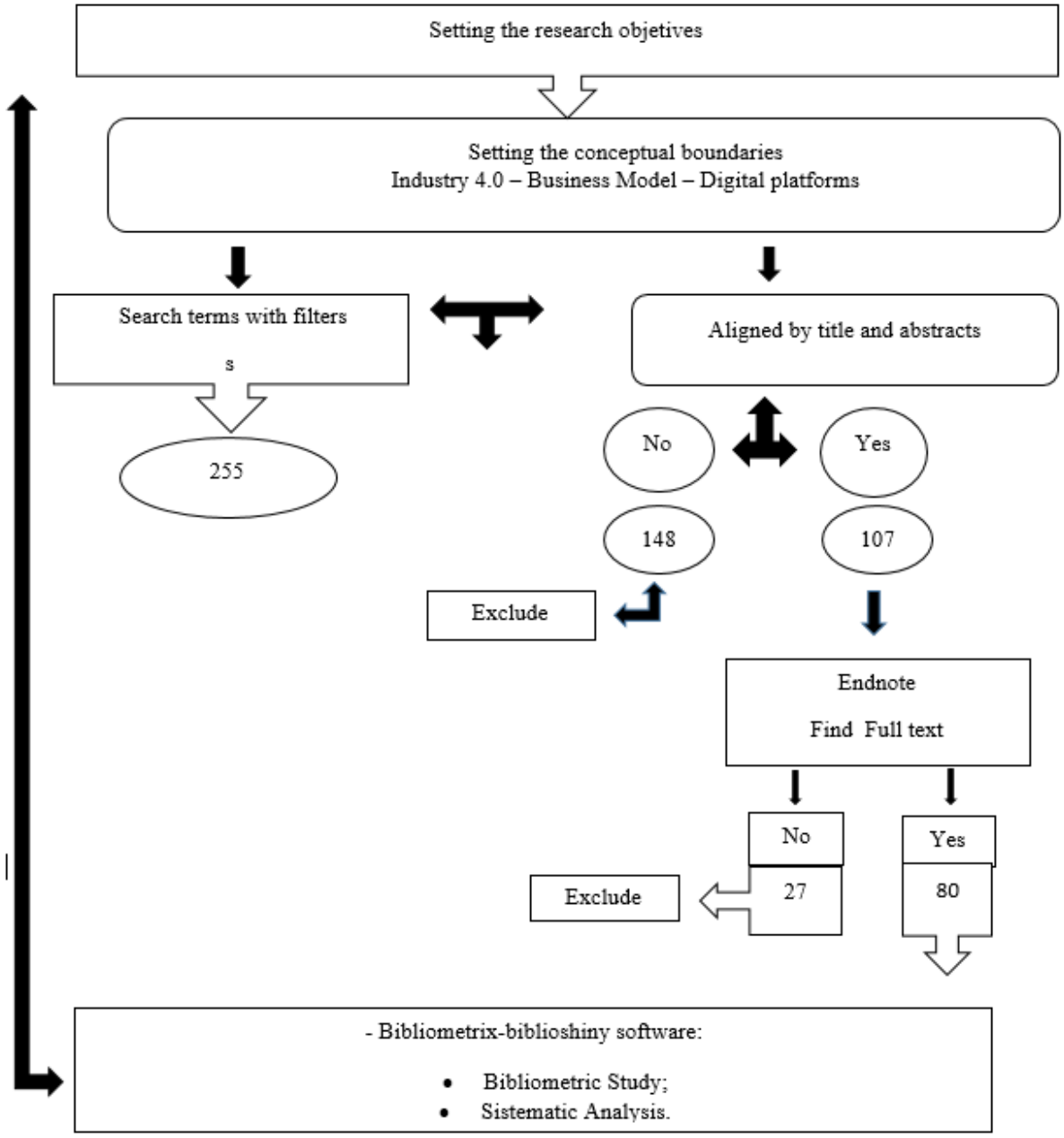
The selection of keywords was restricted to the objectives of the research theme, as well as to the limits of the main concepts that were targeted. After the selection of 255 publications from WoS and from Scopus, a new column was created in the Excel file in order to establish which of these documents are aligned with the theme under analysis and with the main concepts

associated to the theme. The documents were codified in the following way: 0 – to documents not aligned with the title and abstract; and 1 – documents aligned with the title and abstract.

Figure 1 presents the procedures adopted for the selection of the portfolio.

Figure 1

Defining criteria for creating the bibliometric study portfolio



Source: Own elaboration.

The documents aligned with the conceptual axes of the research were N=107. Those documents were exported to the EndNote X9 reference administration software, developed by

Clarivate Analytics (Fitzgibbons & Meert, 2010). The complete text was also extracted. The observations with complete text forming the final portfolio for analysis includes N= 80.

3.3 Execution of the bibliometric research and respective analysis

The bibliometric study used a specialized software tool called Bibliometrix–Biblioshiny. Biblioshiny is a web-based application offering a web interface for Bibliometrix; it is a package developed for the R language, providing a range of tools allowing to produce quantitative analyses and to map data related to bibliometrics and scientometrics (Aria & Cuccurullo, 2017).

Biblioshiny allows three types of metrics: a) Sources; b) Authors; and c) Documents; and to analyses of three knowledge structures: a) Conceptual Structure; b) Intellectual Structure; and c) Social Structure (Aria & Cuccurullo, 2017). These resources allowed to answer questions related to the aims of the present analysis. After reading the documents, the main contributions of these documents for the consolidation of an I4.0-related business model were identified.

4 Results and discussion

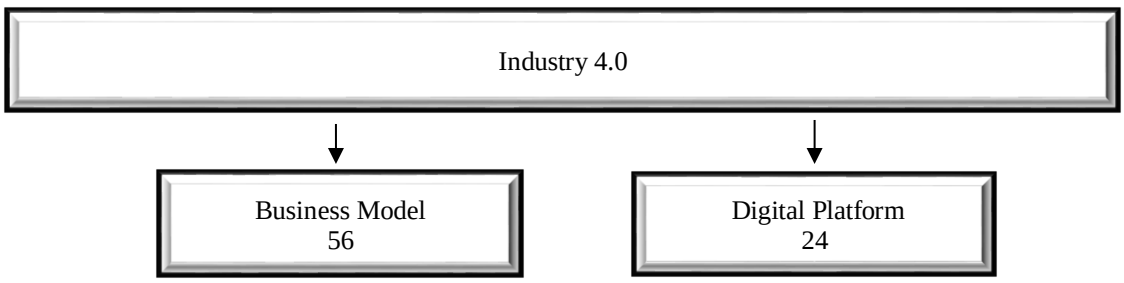
4.1 The interface between Industry 4.0 and digitalization in the construction of new business models: a bibliometric study

4.1.1 Characterization of the publications on Industry 4.0 and digitalization of business models

In the portfolio underlying this study, composed by 80 documents, 8 documents are reviews (9% of the portfolio) and 72 are articles (91%). The search was guided by the key concepts structuring the theme, and for each topic blocs of keywords were established, as per the Methodology explained above: I4.0 combined with Business Models and also with Digital Platforms. Figure 2 presents the number of documents selected within each concept:

Figure 2

Number of documents per conceptual focus

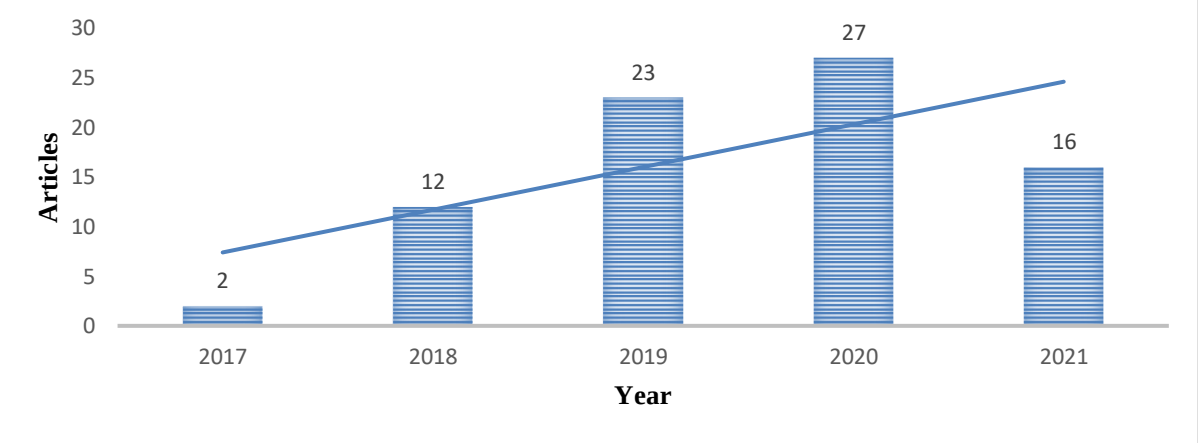


Source: Own elaboration.

The theme I4.0 has been often researched in recent years (Ślusarczyk, 2018), being a recent term (Sung, 2018). The portfolio of 80 documents reflects the growth of the interest of researchers in the topic and in its different 'horizontal' relations with BMs' transformation. The documents sampled are very recent, published between 2017-2021, as Figure 3 shows.

Figure 3

Year of publication of portfolio articles



Source: Own elaboration.

4.1.2 Sources and journals

The 80 documents were published in 51 different scientific journals. Table 2 identifies the most relevant journal according to the number of articles in the portfolio. *Technological Forecasting and Social Change* represented the journal with greater number of publications related to the theme of Industry 4.0 and transformation of business models due to digitalization.

Table 2

Most relevant sources

Ranking	Sources	Articles	Citations	JCR 2020	H-Index
1	Technological Forecasting and Social Change	8	758	9.01	117
2	Journal of Manufacturing Technology Management	6	225	7.33	70
3	International Journal of Production Research	5	758	8.43	142
4	Journal of Cleaner Production	5	86	9.56	200
5	Industrial Marketing Management	3	71	6.86	136
6	International Journal of Production Economics	3	100	8.31	185
7	Polish Journal of Management Studies	3	170	2.28	21
8	Business Process Management Journal	2	85	3.61	81
9	Management (Croatia)	2	1	1.33	-
10	Management Science Letters	2	8	2.06	17

Source: Own elaboration (based on references exported to Biblioshiny).

Table 2 also shows the total number of citations among all articles considered, and the most cited are in the first and third place in this Table. It also presents two measures indicating the Impact Factor, that is, the number of citations and the prestige of such scientific journals, the first measure being the *Journal Citation Report* - JCR and the second the H-index (index created by Hirsh in 2005) (Saad, 2010), that also aims to quantify scientific production according to each paper's number of citations (Dorta-González & Dorta-González, 2011). As per Figure 3 above, there is a growing number of publications since 2017, showing an increased interest of researchers on this topic (Li *et al.*, 2020).

Table 3 emphasizes the most cited publications in this portfolio. The two most cited publications are from 2018 and were published in the *International Journal of Production Research*. Among the top ten selected publications, four among the most cited are from *Technological Forecasting and Social Change*. The publications are very recent, from 2017 until 2019, reinforcing the argument of the growing interest on this topic by researchers in the last years, and the fact that the intensification of digital transformation impacting on business models is still a very under-explored theme (Weking *et al.*, 2020).

Table 3

Most Cited Publications

Ranking	Authors	Title	Publication Name	Year	Number of Citations
1	Kusiak A.	Smart manufacturing	International Journal of Production Research	2018	317
2	Moeuf A., Pellerin R., Lamouri S., Tamayo-Giraldo S., Barbaray R.	The industrial management of SMEs in the era of Industry 4.0	International Journal of Production Research	2018	281
3	Müller J.M., Buliga O., Voigt K.-I.	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Technological Forecasting and Social Change	2018	246
4	Fatorachian H., Kazemi H.	A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework	Production Planning and Control	2018	147
5	Sung T.K.	Industry 4.0: A Korea perspective	Technological Forecasting and Social Change	2018	145
6	Nascimento D.L.M., Alencastro V., Quelhas O.L.G., Caiado	Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal	Journal of Manufacturing Technology Management	2019	128

Ranking	Authors	Title	Publication Name	Year	Number of Citations
	R.G.G., Garza-Reyes J.A., Lona L.R., Tortorella G.				
7	Ślusarczyk B.	Industry 4.0 – Are we ready? [Przemysł 4.0 – Czy jesteśmy przygotowani?]	Polish Journal of Management Studies	2018	126
8	Jabbour C.J.C., Jabbour A.B.L.D.S., Sarkis J., Filho M.G.	Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda	Technological Forecasting and Social Change	2019	92
9	Frank, AG; Mendes, GHS; Ayala, NF; Ghezzi, A	Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective	Technological Forecasting and Social Change	2019	87
10	Schneider P.	Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field	Review of Managerial Science	2018	83

Source: Own elaboration.

4.1.3 Most cited authors

This section identifies the most relevant authors in the portfolio. The selection is ordered according to the number of published articles. Müller is both the author with more articles and the author with the greater number of citations, as Table 4 below shows.

Table 4

Most relevant authors

Ranking	Author	Articles	Citations
1	Müller J. M.	5	345
2	Gebauer H.	4	165
3	Voigt K. I.	4	294
4	Matthyssens P.	3	44
5	Mihardjo L. W. W.	3	20
6	Parida V	3	131
7	Alamsjah F.	2	20
8	Ayala N. F.	2	179
9	Buliga O.	2	287
10	Coreynen W.	2	13
11	Frank A. G.	2	179
12	Kohtamaki M.	2	127
13	Machado M. C.	2	40
14	Queiroz M. M.	2	40
15	Sarkis J.	2	135

Ranking	Author	Articles	Citations
16	Schmidt M. C.	2	7
17	Telles R.	2	40
18	Veile J. W.	2	7
19	Wuest T.	2	8
20	Abad F. J.	1	25

Source: Own elaboration (based on references exported to Biblioshiny).

4.1.4 Affiliation and most frequent institutions of authors and countries of scientific production

Table 5 identifies the most relevant institutional affiliations considering all authors of the portfolio, and the respective number of publications.

Table 5

Most relevant author affiliations

N	Affiliations	Country	Articles
1	Bina Nusantara University	Indonesia	10
2	Universitas Indonesia	Indonesia	9
3	Friedrich- Alexander University Erlanger-Nürnberg	Germany	8
4	Beihang University	China	6
5	Sumy State University	Ukraine	5
6	University of Bergamo	Italy	5
7	Halmstad University	Sweden	4
8	Technical University of Munich	Germany	4
9	Universidad de Cádiz	Spain	4
10	Universidade Federal do Rio Grande do Sul	Brazil	4
11	Universidade Tecnológica Federal do Paraná (UTFPR)	Brazil	4
12	Western Sydney University	Australia	4
13	Zhejiang University	China	4

Source: Own elaboration (based on references exported to Biblioshiny).

However, the countries with the greater number of documents cited are different than the countries with greater scientific production. The most cited countries where authors are based are: 1st) France, 2nd) Germany and 3rd) USA. Table 6 presents the top ten of such countries.

Table 6

Most cited countries of authors

N	Country	Total Citations
1	France	403
2	Germany	391
3	USA	368
4	United Kingdom	289
5	Brazil	219
6	Finland	134
7	Poland	133
8	Italy	104
9	China	68
10	Spain	34

Source: Own elaboration (based on references exported to Biblioshiny).

4.1.5 Co-occurrence of authors' keywords

Authors' keywords are the terms authors consider to better represent their publication. They should be analyzed with prudence, as Biblioshiny has a limitation of analysis of verbal and plural combinations of the words (Aria & Cuccurullo, 2017). Table 7 indicates the top 10 keywords that authors used with greater frequency in this portfolio.

Table 7

Most frequent authors' keywords

N	Keywords	Frequency
1	Industry 4 0	48
2	Business Model Innovation	8
3	Digital Transformation	7
4	Servitization	6
5	Business Model	5
6	Circular Economy	5
7	Digitization	5
8	Internet of Things	5
9	3D Printing	4
10	Additive Manufacturing	4

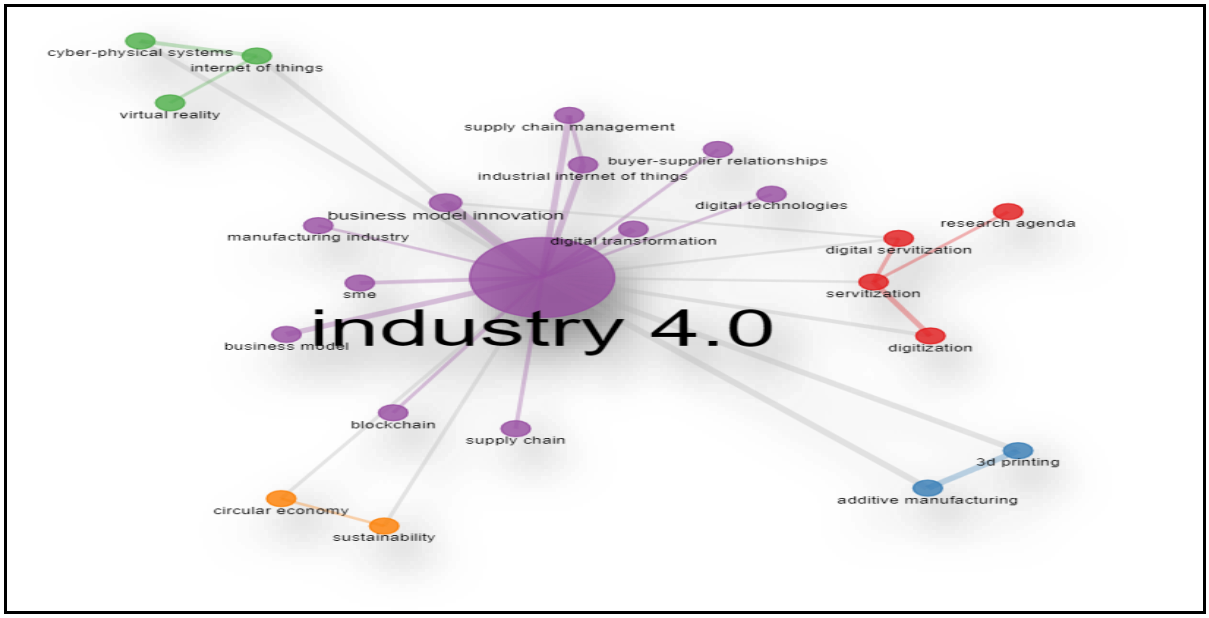
Source: Own elaboration (based on references exported to Biblioshiny).

Authors' keywords help to clarify the main topics of the theme under research and how they are related. To complement the research, the networks between the co-occurrences of these keywords were mapped. The software maps clusters of keywords according to the proximity of

keywords' appearance, allowing insights about the associations between these topics. Figure 4 presents the network of keywords about the theme Industry 4.0 and digitalization of BMs.

Figure 4

Network of the occurrences of the keywords (defined by authors)



Source: Own elaboration (based on references exported to the Biblioshiny).

Five main clusters were detected in the network, structuring the main theme on I4.0 and digital BMs:

- *Cluster 1*: Industry 4.0; Business Model; SME (Small and Medium Enterprise); Manufacturing Industry; Business Model Innovation; Digital Transformation; Industrial Internet of Things; Supply Chain Management; Buyer-Supplier Relationships; Digital Technologies; Supply Chain; *Blockchain*.

Industry 4.0 involves an array of digital Technologies, that impact the production process, the relationships and communication between producers, suppliers and consumers (Llopis-Albert *et al.*, 2021). The main digital technologies on which Industry 4.0 is based, which enable innovative business models, are emphasized: IoT, cloud-based services, big data & analytics (Frank *et al.*, 2019).

Moreover, technologies like *blockchain* offer a variety of uses in distinct economic segments in the digitalized economy (Kim, 2020) - it is the basis for cryptocurrencies but also is used, for instance, for traceability and for smart contracts applicable in any

sector. *Blockchain* represents a decentralized ledger and a platform to execute automatized smart contracts in the supply chain (Dolgui *et al.*, 2020), facilitating the applications in the sharing economy without the need for a central entity (Esmaeilian, Sarkis, Lewis, & Behdad, 2020).

The main studies included in this portfolio also signal that SMEs implement only some of the digital technologies related to I4.0 (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018; Müller, 2019; Müller, Buliga, & Voigt, 2018).

- *Cluster 2:* Cyber -physical systems; internet of things; virtual reality.

According to Weking et al. (2020), IoT, CPS and the Smart Factory are the main facilitators and/or technological enablers for I4.0-relates business models (I4.0 BMs). I4.0 brings together several complementary and overlapping technologies (Gottge et al., 2020). Such digital technologies are a crucial for BMI thought for digital platforms (Menon, Kärkkäinen, & Wuest, 2020) connecting distinct actors and physical and digital resources, increasing scale and intermediating (Tian *et al.*, 2021) relationships between buyers and suppliers along the supply chain (Veile, Schmidt, Müller, & Voigt, 2020).

- *Cluster 3:* Addictive Manufacturing; 3D Printing.

The introduction of additive manufacturing in the productive process allows to reduce costs, as well as to offer greater customization of products via the use of 3D printing (Florén, Barth, Gullbrand, & Holmén, 2021; Nascimento *et al.*, 2019). Furthermore, new materials are combined and tested with Key Enabling Technologies (KETs) with horizontal applications in different sectors, like nanotechnology, laser technology, industrial biotechnology, 3D printing and artificial intelligence (Götz, 2021).

- *Cluster 4:* Digitalization; Servitization; Digital Servitization; Research Agenda.

New discussions about digital business models for servitization are analyzed by Kohtamäki, Parida, Oghazi, Gebauer, and Baines (2019, p. 383), which use the definition "*digital servitization as the transition toward smart product-service-software systems that enable value creation and capture through monitoring, control, optimization, and autonomous function"* (p. 383). Servitization does not involved necessarily digitalization, even though digital has been utilized to alter BMs. Digitalization is a strategy offering ample opportunities for different economic agents –

such as distributors and retailers – and even new entrants without specific (own) products may offer digital platforms to connect suppliers and clients (Coreynen, Matthyssens, Vanderstraeten, & van Witteloostuijn, 2020). The grouping underlying this cluster corroborates the recent study by Agostini and Nosella (2021), who identify a cluster that reunites servitization and IoT. The integration between digital platforms and servitization is suggested in several publications as a relevant focus for future research, as the study of these interactions has deemed promising.

- Cluster 5: Circular Economy; Sustainability.

In the relevant business and economic literature, studies about innovative BMs are not recent. However, these studies gained academic attention currently and relevance, for instance associated to sustainability and circular economy models (Das, Perera, Senaratne, & Osei-Kyei, 2020; Nascimento *et al.*, 2019). The effect of digital technologies on sustainability performance needs to be properly understood through a well-established supply chain platform (Li *et al.*, 2020). New business models designed to fulfil objectives of sustainability and circularity will depend on the efforts of distinct *stakeholders.* Jabbour, Jabbour, Sarkis, and Filho (2019) propose a BM characterized by the integration of the circular economy and the use of big data.

4.2 The convergence of Industry 4.0 technologies and the digitalization of I4.0 BMs

In Table 8 some studies were selected, aiming to present, define, characterize of provide associations and impacts of I4.0 on new BMs. We found 24 studies focused strictly on the link between I4.0-BM. Table 8 below reports the top ten articles in the portfolio.

Table 8

Selected studies relating I4.0 and BM

N	Authors	Study objectives related to BM and I.40
1	Safar *et al*. (2018)	They analyzed how such platforms and Industry 4.0 will change the business environment and business models, with emphasis on SMEs. The study proposes a business model architecture for the functioning of a smart factory.
2	Müller, Buliga, and Voigt (2018)	They discussed the main effects of Industry 4.0 on the business models of manufacturing SMEs.
3	Nascimento *et al*. (2019)	They address a business model proposal that allows for the involvement of technologies associated with I4.0 in the circular economy in manufacturing specifically.
4	Frank *et al*. (2019)	The article provides an interface between servitization and Industry 4.0 through a conceptual framework from an innovative business model (BMI) perspective.
5	Bagnoli, Dal Mas, and Massaro (2019)	The authors analyzed the impacts of I4.0 on business models.
6	Jerman, Erenda, and Bertoncelj (2019)	They presented the impact of I4.0 on the BM in a smart factory.
7	Weking *et al.* (2020)	They developed a taxonomy to characterize business models for Industry 4.0 (I4.0 BMs) and derive 13 standards for I4.0 BMs.
8	van Tonder (2020)	They created a framework for businesses to digitize and innovate the BMs.
9	Müller, Buliga, and Voigt (2021)	They analyzed how companies' absorption capacity of new business models, especially those created after I4.0; differentiate the strategies of SMEs and large companies.
10	Cucculelli, Dileo and Pini (2021)	They investigated family-run businesses and the adoption of I4.0 BM. The authors argue that family businesses are weak in adopting business model 4.0. However, when the triple helix relationship to strengthen small businesses enters the scene, the disadvantages disappear compared to the participation of institutes and universities helping family managers.

Source: Own elaboration. (Appendix 1 - full table).

The insertion of digital and other emerging technologies based on Industry 4.0 creates new BMs (Li *et al.*, 2020), which Cucculelli, Dileo, and Pini (2021) denominate "I4.0 BMs". But, after all, what is a 4.0 business model?

Das *et al.* (2020) argue that business models and I4.0 are scarcely studied currently in certain sectors. Yet, these opportunities to implement new and innovative BMs generated by I4.0 is limited by the absorptive capacity of firms (Müller *et al.*, 2021). Weking *et al.* (2020) analyze I4.0 BMs as a result of innovative business models (BMIs).

The main changes in BMs for intelligent firms are categorized by Jerman, Erenda, and Bertoncelj (2019): a) automation, robotics and digitalization ; b) integration of workers, machines and products; and c) redefinition of the role of jobs, machines and products in the factory.

Weking *et al.* (2020) are the precursors in trying to characterize a 'standard' BM for I4.0. They identify three 'super-patterns' and 10 'sub-patterns' of I4.0 BMs. "The super-pattern integration innovates its BM around new processes, servitization around new products and specialization around a hybrid of products and processes" (p. 8). The integration of BMs covers the majority of the value chain

and provokes changes. The pattern integration also presents three sub-patterns: *crowndsourced innovation*, production as a service and mass customization. These integrated patterns are able to cause great changes in the relationships between clients, production and distribution. Owing to the ability of such model to mass customize its products, the firm may relocalize production back to the home country, even with high salaries practiced in those firms' countries, for several small companies.

Industry 4.0 describes the process of digitalization of industrial manufacturing (Weking *et al*., 2020). Digitalization does not have effects only in the individual BMs of firms, it also involves the alignment of other firms belonging to the ecosystem (Kohtamäki *et al.*, 2019). Meanwhile, generating profit with BMs is complex and, very often, firms invest in digital technologies without considering all implications of digitalization, and in these cases the return is often modest or negative (Linde, Sjödin, Parida, & Gebauer, 2020).

The proposition of a BM considering the aspects inherent to I4.0 is established by Safar *et al.* (2018), including and being supported by these different elements: a) value proposition; b) value creation and c) value capture. And includes 6 conceptual levels: I) Interoperability: establish common communication between machines and humans; II) Virtualization: generates a virtual model of a smart factory – a *digital twin*; III) Real Time: data are processes in real time; IV) Modularity: easy adaptation and flexibility in the firm *vis-à-vis* different and new demands; V) Decentralization and VI) Supply of the product/Service: decisions need to be qualified to maximize production. That must stimulate the firm to increase its competitiveness both in the local and in the international market.

SMEs are not exploring all I4.0 technologies, and I4.0 implementation is mainly oriented towards cost reductions, and to monitoring production processes; thus, there is no evidence of a real transformation of their BM (Moeuf *et al.*, 2018). This observation corroborates the research of Müller *et al.* (2021), which notes that I4.0 is, often, considered by SMEs a way to improve efficiency but not to create other BMs. This makes it necessary for the Government to implement support policies to provide information on best practices, financial resources, access to an intersectoral and regional network of specialized partners (Yang, Kim, & Yim, 2019).

Safar *et al.* (2018) propose a BM for SMEs with a perspective to implement a platform introducing IoT in the firm in order to create the smart environment communicating clients, suppliers, banks, insurance providers (including authorities such as financial authorities in order to connect the already standardized software, and to store masses of data in the cloud). That is, authors have understood the difficulty and the pre-requisites to implement a BM in SMEs, and developed a model with a focus on communication of the firm with the external environment; moreover, a socio-technic system integrating the technologies used by I4.0 is also long-awaited.

5 Conclusions, trends and limitation

This bibliometric study allowed answering several interrogations about the research field under analysis. The article explored the metadata of the publications aiming to better understand the developments in the research about the interface I4.0-BM-DBM. In this way, this paper also advances with exploring and systematizing I4.0 BMs.

Although there are many publications about I4.0, especially focused on discussing the impact of digital and I4.0-related technologies, there are few papers trying to characterize a I4.0 BM, or a consolidated model. The recent article by Agostini and Nosella (2021) also identified this gap in the literature. This is due to the fact that advances in the research about BMs and I4.0 have focused on isolated technologies and their influence and impact in distinct economic segments. In our systematic literature review, we single out the contribution of the work by Weking *et al.* (2020) in trying to identify patterns for a I4.0-specific BM.

Although the main digital technologies and other emerging technologies associated to I4.0 may lead to totally disruptive BMs, extant literature indicates that the adopted BMs consist in the adoption of usually only one or a few of those digital technologies, with the aim of improving incrementally one or some of the processes/products/services of the firm, not targeting or trying to implement a truly innovative BM. That occurs mainly with SMEs.

Two avenues of research were identified within the overarching theme studied, which should generate greater attention among the I4.0 *stakeholders*: a) the relation between servitization and digital technologies in the perspective of the supply of smart products and services; b) sustainability and circular economy in a I4.0 BM. These are thematic axes that do not need necessarily to be digitalized to function, although once incorporated, technologies I4.0 may create a more innovative and impactful BM.

The main limitations occurred in the I4.0-BM-DBM interface. There is ample research in each isolated bloc, yet that interface has been very scarcely explored. Hence, this bibliometric study, while providing a worthwhile contribution, needs to be critically interpreted as far as the pointers evidenced by the metadata are concerned.

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Appendix 1

Articles with the purpose of study related to business models and I.40

N	Authors	Study objectives related to BM and I.40
1	Safar *et al.* (2018)	They analyzed how such platforms and Industry 4.0 will change the business environment and business models, with emphasis on SMEs. The study proposes a business model architecture for the functioning of a smart factory.
2	Moeuf *et a.l* (2018)	The results detected that SMEs do not explore all I4.0 technologies, and implementation of I4.0 technologies are only oriented towards cost reduction mainly to monitor production processes. There is no evidence of a real transformation in the business model.
3	Müller, Buliga, and Voigt (2018)	They discussed the main effects of Industry 4.0 on the business models of manufacturing SMEs.
4	Müller (2019)	The study addressed the effects of Industry 4.0 on business models, especially for SMEs.
5	Nascimento *et al.* (2019)	They address a business model proposal that allows for the involvement of technologies associated with I4.0 in the circular economy in manufacturing specifically.
6	Jabbour *et al.* (2019)	The authors propose a business model based on the integration of the circular economy and the use of big data.
7	Frank *et al*. (2019)	The article provides an interface between servitization and Industry 4.0 through a conceptual framework from an innovative business model (BMI) perspective.
8	Kohtamäki *et al.* (2019)	They studied servitization for digitized business models from an ecosystem perspective.
9	Mihardjo *et al.* (2019)	They analyzed the role of digital leadership and its ability to influence the customer experience orientation for developing business model innovation based on I4.0.

N	Authors	Study objectives related to BM and I.40
10	Bagnoli, Dal Mas, and Massaro (2019)	The authors analyzed the impacts of I4.0 on business models.
11	Jerman, Erenda, and Bertoncelj (2019)	They presented the impact of I4.0 on the BM in a smart factory.
12	Yang, Kim, and Yim (2019)	They described the Korean government's Flagship Project Support Program (FPSP), which supports latecomers in creating open platforms and creating new business ideas in innovative technology industries.
13	Caliskan and Ozturkoglu (2020)	They presented a study on changes in marketing from the perspective of I4.0 and the transformations caused by the digitization of business models.
14	Das *et al*. (2020)	The study objective was to develop a canvas analysis model to help the construction industry segment with the use of I 4.0 enabling technologies.
15	Weking *et al*. (2020)	They developed a taxonomy to characterize business models for Industry 4.0 (I4.0 BMs) and derive 13 standards for I4.0 BMs.
16	Linde *et al.* (2020)	They identified three pitfalls of digitization and devised a framework that companies can assess opportunities for digital business models and make a decision.
17	Dressler and Paunovic (2020)	The study addresses the innovative business model based on I4.0 for the wine segment.
18	van Tonder (2020)	They created a framework for businesses to digitize and innovate the BMs.
19	Müller, Buliga, and Voigt (2021)	They analyzed how companies' absorption capacity of new business models, especially those created after I4.0; differentiate the strategies of SMEs and large companies.
20	Cucculelli, Dileo and Pini (2021)	They investigated family-run businesses and the adoption of I4.0 BM. The authors argue that family businesses are weak in adopting business model 4.0. However, when the triple helix relationship to strengthen small businesses enters the scene, the disadvantages disappear compared to the participation of institutes and universities helping family managers.
21	Del Giudice *et al.* (2021)	They studied how digital innovation is influenced by the three self-tuning models for smart manufacturing SMEs.
22	Pizzi, Corbo, and Caputo (2021)	They analyzed Fintech, an example of sectors developed under the influence of Industry 4.0, can play a relevant role in the transition of SMEs to a more sustainable business model, leading to a better integration of circular economy practices.
23	Tian *et al.* (2021)	It explored how companies successfully leverage platforms for servitization, adapting their business models in an Industry 4.0 context.
24	Florén *et al.* (2021)	The authors prepared a literature review on the intersection between additive manufacturing and business models.

Source: Own elaboration.