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Article

Business Models in the Industry 4.0 Environment—Results of Web of Science Bibliometric Analysis

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Abstract: The Fourth Industrial Revolution affects the operations of companies and results in new strategic thinking. The changes resulting from the requirements of Industry 4.0 force restructuring in many areas of management or the building of new business models. The aim of this article was to indicate the pillars that will form the basis for building business models of enterprises functioning in the era of Industry 4.0. The research methods used in this article were bibliometric analysis and analysis of the content of sophisticated publications. The results of this research are the analysis of the dynamics of publications in the area of business models in the era of Industry 4.0, an indication of the research areas undertaken in these publications and the identification of the pillars that will constitute the basis for building business models in the era of Industry 4.0. Business models in the era of Industry 4.0 are to be a method of increasing and using the company's resources in order to achieve a competitive advantage through personalization of products and their new quality; their key competitive advantage will be a structure based on a network of cyber-physical cooperation. This article is dedicated to scientists and business practitioners looking for tips for building modern business models.



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Keywords: business model; open business model; Industry 4.0; Fourth Industrial Revolution; pillars of the business model; open innovations

1. Introduction

The Fourth Industrial Revolution refers to the social, industrial and technological changes caused by the digital transformation of industry, which are identified with the concept of Industry 4.0 [1,2]. Industry 4.0 means the integration of intelligent machines and systems and the introduction of changes in production processes to increase production efficiency and introduce the possibility of flexible changes in their scope [3–5].

The use of state-of-the-art technological solutions on an ever-wider scale and the networking of the economy, which has an impact on the development of various forms of communication, competitiveness on a global scale and the increasing and more popular mobility of employees, are the trends and phenomena that affect people's lifestyle and work and thus have an impact on the functioning of companies [6–10]. These patterns, combined with the rapidly changing professional environment, mean new opportunities and challenges for companies [11–16].

In the future business reality, what was previously a domain of many market participants will be offered within one application by one player. Trends will be shaped by customer expectations and experiences, creating the potential to transform almost any sector within the business-to-business (B2B) and business-to-customer (B2C) areas [17–19]. As a result, companies will have to define their strategies and business models in a completely different way over the next few years—not concerning traditional market competitors but

the emerging consumer ecosystems [20–23]. New business concepts enable the creation of new business models, including open business models using open innovation. These models are the strategic and operational basis for changes in the configuration of products and processes in an enterprise. These models become the foundation of a competitive market advantage determined by the rules of the Industry 4.0 concept [24]. Dynamic technological development and solutions implemented in modern companies result in a change in management paradigms and the need to build new business models based on maintaining a balance between the development of autonomous (intelligent) technology and remote communication systems and the quality of life, and recognized values in different societies [25]. What distinguishes the Fourth Industrial Revolution is the knowledge of customer needs, which constitutes a competitive advantage of enterprises—correctly defining the opportunities, challenges and problems that it brings guarantees conscious use of new opportunities or new market opportunities [26,27].

The literature analysis identified a research gap in the lack of business models of enterprises operating in Industry 4.0, mainly the structure of the models, the pillars and the sources of their competitive advantage. This article aimed to indicate the pillars that will form the basis for building enterprises' open business models in the Industry 4.0 environment. To achieve this aim, the following research questions were formulated:

1. How does Industry 4.0 affect business models?
2. What are the key pillars of Industry 4.0 affecting new business models?

The authors' scientific contribution is to demonstrate the multidisciplinary nature of business models in the era of Industry 4.0 and to identify the pillars from which they will be built. This knowledge can provide important guidance for researchers but also business practitioners looking for guidelines for building open business models in the era of the Fourth Industrial Revolution.

This article is organized as follows: The second section describes Industry 4.0 and open business model assumptions. The third section presents the research methods. The fourth section of the article presents the research results and discussion. The discussion focuses on the business models of enterprises operating in the era of the Fourth Industrial Revolution. The final section of this article presents the conclusions.

2. Industry 4.0 towards Open Business Model

The Fourth Industrial Revolution is a term for the social, industrial and technological changes brought about by the digital transformation of industry. The name Industry 4.0 has been adopted in Europe, emerging from the German government's work in 2010 to identify and analyze upcoming disruptive changes of strategic importance to the German economy. The term was used for the first time at the Hanover Fair in 2011 during the presentation of the industry's future [28–30]. Industry 4.0 is a subset of the Fourth Industrial Revolution. Customers and business partners are directly involved in business processes and value creation. Production is combined with high-quality services. In the future, with intelligent monitoring and decision making, companies and their entire networks should be able to control and optimize their operations almost in real time. Industry 4.0 is an upheaval in production control methodologies [31,32].

Industry 4.0 is essentially a trend towards automation and data sharing in manufacturing technologies and processes, including cyber-physical systems (CPSs), the Internet of Things (IoT), cloud computing, cognitive computing and artificial intelligence. The main advantages of Industry 4.0 are as follows [33,34]:

- Increased economic efficiency;
- Increased work efficiency;
- Increased flexibility;
- Reduction in production costs;
- Increased return on investment.

In the Fourth Industrial Revolution, the relationship between human capital and technological capital is modified. Automation of technical capital translates into a high quality of products and services. The increase in work efficiency is achieved primarily through an automatic or semi-automatic decision-making process [35,36]. Production is monitored, and it is much easier to bring new products to the production line and create opportunities for a single production operation. Production becomes flexible, and the factory becomes intelligent [37,38].

By linking an increasing number of industries to society, technology can influence production's functionality and quality and quantity [39]. Industry 4.0 forces the implementation of modern IT solutions across the entire value chain, making it possible to produce personalized products for a specific customer and related value chains. Advanced information and communication technologies allow production to be precisely tailored to customer expectations while maintaining low costs, high quality and efficiency. Modern technology-based business models are accelerating the transformation of the industry, changing the market structure. This poses new challenges for many areas of management, which is forced to adapt to the digital world architecture [40,41].

Business models developed and implemented by companies determine their profitability and competitiveness. New strategic behavior is determined by the changes that can be observed in modern business. Currently, managers are required to use increasingly sophisticated management methods and concepts [42]. Analyzing the essence, structure and types of strategic models is an essential cognitive element of the sphere of development and operation. Such research also serves to improve existing business models and even build new models, which become necessary in the face of challenges and market volatility. The progressive globalization and networking of the economy make it necessary to create new business concepts. Their theoretical detail and, at the same time, the possibility of application are concepts of business models whose important element are business processes, which are, to some extent, a way of realizing value in the form of relationships with customers, particularly providing them with products that meet specific needs [43,44].

The company's business model is presented as a set of activities, methods and timescales, using its resources to create the highest value for the client and secure its position to take over the value. Innovations can be applied to all business model elements and are essential for creating value for the customer. The business model reflects the implementation of the strategy in terms of economic effects. The role of the strategy is highlighted in the model because current and future revenues are generated by the products offered to customers and the competitive approach to the market. This results in a revenue stream and a return on investment, thanks to a combination of profit and an appropriate cost structure [45]. Thus, the business model is the configuration of the strategy with regard to the sources of income and profits [46,47].

Industry 4.0 technologies are creating new opportunities for businesses, greatly facilitating open business models based on open innovation. In open business models, collaboration with partners within cyber-physical systems becomes a key source of value creation and capture. They help create value by leveraging a large number of ideas, including external outsiders [48–50]. They also allow for greater value capture by leveraging a company's key assets, resources or positions not only in its own business, but also in the business of other companies [51–56]. Companies with an open business model actively seek innovative ways to collaborate with all business partners: suppliers, customers or general partners, to expand their business, e.g., through servitization. In such a model, open innovation is integrated into the business model [57,58]. Different revenue generation methods are used. Diversification of revenue methods reduces risk and provides multiple paths to sustainable growth. Open business models start with participation, universal access and inclusivity [59]. Open innovation seems to be a natural direction of change in the evolution of business models of the Fourth Industrial Revolution era. The relationship of open innovation to open business models is very important because of the ideas of

knowledge sharing, finding solutions that generate profit for the company and society, product responsibility and listening to the voice of stakeholders [60–69].

Industry 4.0 requires the development of open business models that support the implementation of open innovation. Hence, this article carried out a bibliographic analysis in order to identify the current results of research in this area and to identify key areas of interest undertaken in selected scientific articles. The analysis sought answers to the following specific questions:

1. What is the total number of publications in the areas of “business models”, “Industry 4.0” and “business models and Industry 4.0”?
2. What is the ranking of researchers in terms of the number of publications and citations?
3. Which countries are leading in addressing the described topics?
4. Which research centers are leading in conducting research?
5. Which journals and conferences have addressed the issues under consideration?
6. Which research areas can be considered key based on the content of selected publications based on the criterion of “Highly Cited Paper”?
7. Which pillars of business models in the Industry 4.0 era are recognized in the selected papers?

Obtaining answers to the above questions will allow us to achieve the goal of this article, that is, to indicate the pillars that will form the basis for building enterprises’ open business models in the Industry 4.0 environment.

3. Materials and Methods

This paper used bibliometric analysis, which is considered as a method of evaluating research results and gaining a comprehensive view of the current scientific output. It involves the use and quantification of quantitative data in scientific work and quantitative indicators of various databases [70–73]. Bibliometric research is often used by researchers, public institutions, universities and enterprises. With the help of quantitative analysis, it is possible to study market trends and the dynamics of the development of thematic papers in a particular area [74].

Systematic literature network analysis (SLNA) was adopted as the method of bibliometric analysis. This approach identifies critical trends and issues that affect knowledge development in a given field more scientifically and objectively than descriptive reviews. It focuses on the classification of the research input and subjective criteria for selecting papers [75].

The publication search was conducted using the Web of Science (WoS) Core Collection, a database from Clarivate Analytics. All publications that were written in English were searched. The Web of Science database was used for the bibliometric analysis because it is an interdisciplinary research platform that registers more than 12,000 journals with international reach and more than 160,000 conferences, including international conferences, worldwide. This database allows users to search multiple databases simultaneously from a single interface—through the Web of Science™ Core Collection. It collects many bibliometric indicators and studies from most disciplines. It is also the most widely used database of data and citations for scientific purposes [76]. The most significant advantage of this database is its transparency and orderliness. The Web of Science database is considered one of the most consistent databases of scientific publications [77]. Figure 1 shows the adopted research methodology.

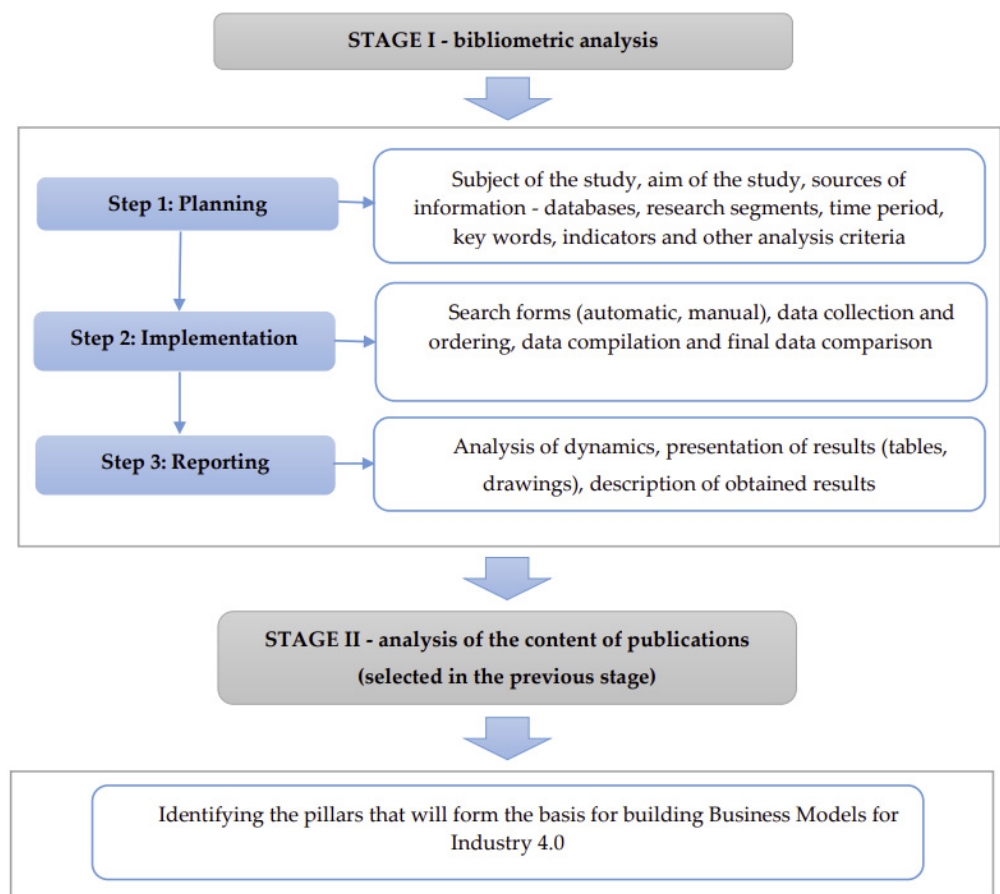


Figure 1. Research methodology. Source: own elaboration.

The knowledge base related to the research on business models and Industry 4.0 is spreading significantly. The trend of publishing scientific papers on these areas is constantly growing, which indicates that research on the concept of business models and Industry 4.0 is still in the focus of scientists and researchers. Therefore, the current state of knowledge requires research to systematize and rationalize the created knowledge on this subject. The study of the knowledge creation process, transfer and development from a dynamic perspective will reveal its evolution over time. This bibliometric research was focused on three thematic/research areas (Figure 2):

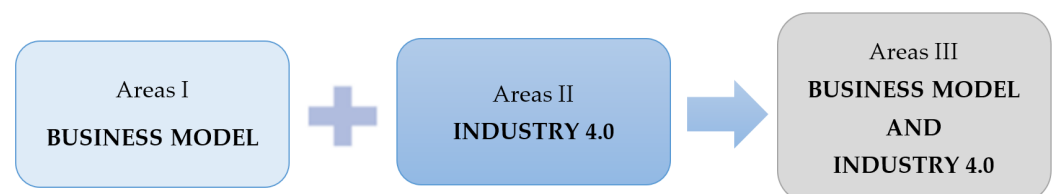


Figure 2. Areas of bibliometric analysis. Source: own elaboration.

Area I—Business Models (with open business models). This was the most extensive area covering the time span of the analyzed period from 1 January 1996 to 31 October 2021. Before 1996, there were single publications from this area, but due to their small number, the earlier years were not taken into account.

Area II—Industry 4.0, whose time span in the analyzed period is 1 January 2011 to 31 October 2021. This research area started in 2011 when German experts introduced an industry development strategy based on intelligent technology.

Area III—Business Models and Industry 4.0. The time span of the analyzed period is 1 January 2011 to 31 October 2021. It was assumed that business models in the Industry 4.0 era are a form of evolution of previous business models, absorbing the Industry 4.0 components and flexibly adapting to new market conditions resulting from the concept of Industry 4.0, currently also known as the Fourth Industrial Revolution.

The identification of thematic/research areas is a critical stage of analysis, and its results may change if different keywords are used. Finally, the searches were conducted on 3 November 2021 in Web of Science using selected keywords. The three defined research areas were searched in the category “Topic”, which includes: title, abstract, keywords defined by the author(s) and keywords plus (so-called “KeyWords Plus”—words and phrases extracted from the titles of cited articles).

4. Results

Table 1 shows the WoS database search results for the three subject areas studied. However, the dynamics of growth of interest in the researched areas are shown in Figures 3–5.

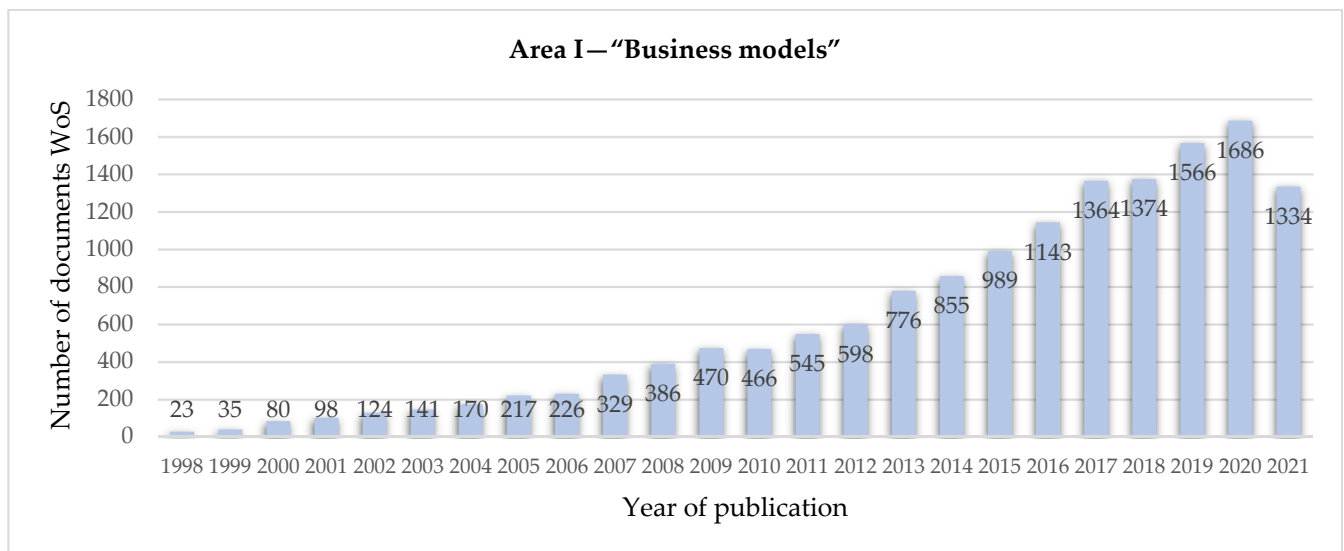


Figure 3. The dynamics of growth of published articles in the WoS database from 1 January 1996 to 31 October 2021 in the field of business models. Source: own elaboration.

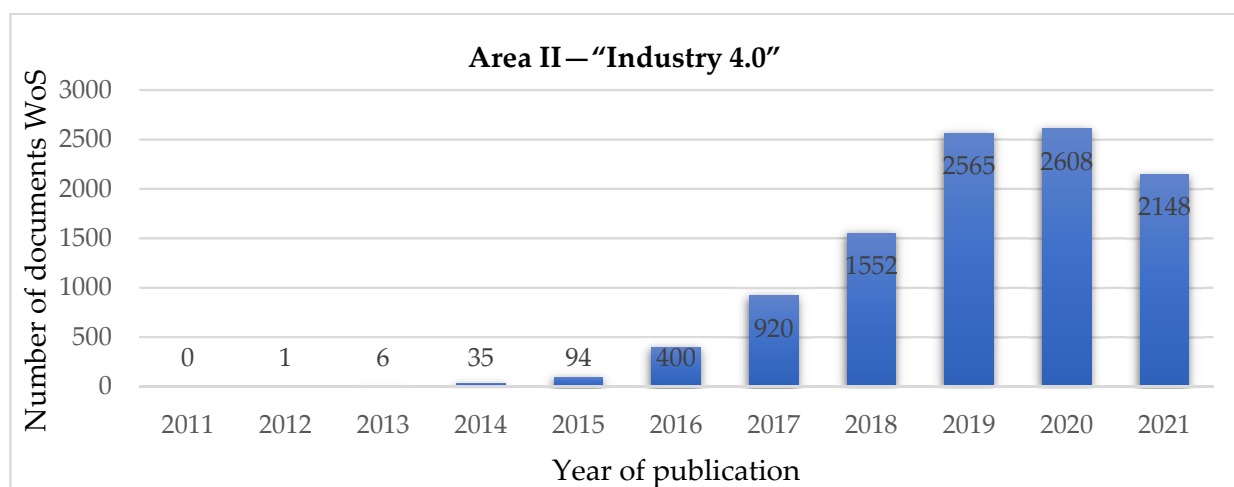


Figure 4. Growth dynamics of published articles in the WoS database from 1 January 2011 to 31 October 2021 in the field of Industry 4.0. Source: own elaboration.

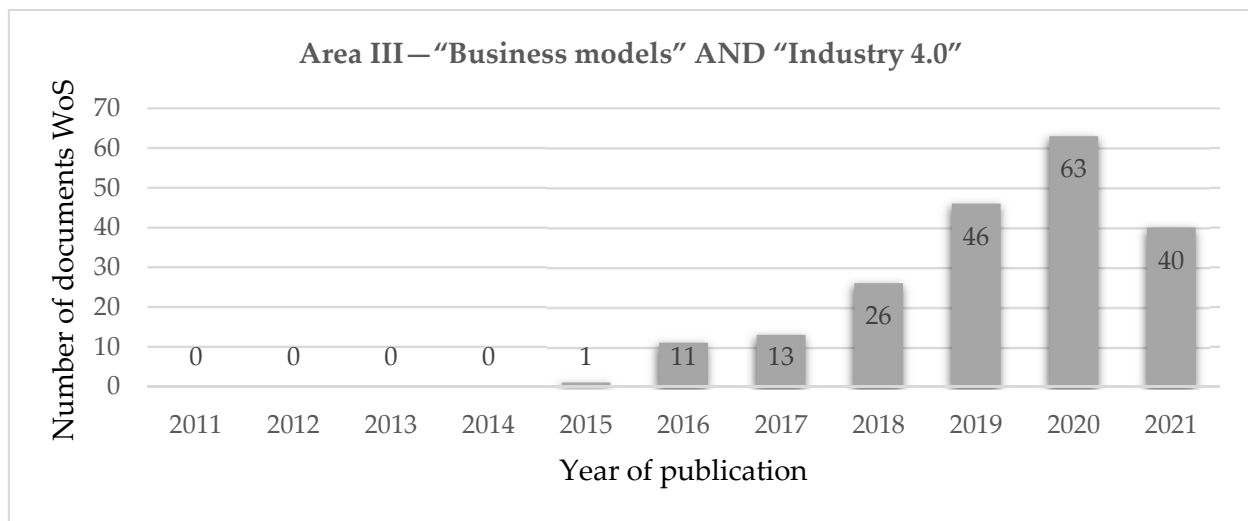


Figure 5. Growth dynamics of published articles in the WoS database from 1 January 2011 to 31 October 2021 in the field of business models and Industry 4.0. Source: own elaboration.

Table 1. Search results for each area.

Research Area	Search Results (Number of Documents)
Area I—Business Models	15.031
Area II—Industry 4.0	10.329
Area III—Business Models and Industry 4.0	200

The review of the dynamics of the number of published scientific papers from the studied areas from 1 January 1996 to 31 October 2021 indicates that the studied areas are still current, and interest in them is growing dynamically. Assuming four periods of time—emergence (the time of appearance of a new area), definition (the time when a new research area is already defined by many researchers taking into account different areas of knowledge), maturity of a concept (the time when a concept is already well known and described) and stabilization (the time when a concept is already firmly established in science and has even undergone multidirectional development), the following can be considered:

- The area of “business models” already emerged in 1996. When the first publications were published to reflect on the new form of management, there were several of them on an annual basis. Currently, this area is at the end of the definition period, gradually moving to maturity; however, the concept of management through the definition of a business model still requires multi-faceted research and is intensively explored by researchers. Many researchers have defined the business model concept and identified its components that are essential for managing a company in a turbulent, competitive environment. Since 2015, the number of publications in this area has started to exceed one thousand, and the description of business models has become increasingly complex, multidimensional and multi-faceted.
- The “Industry 4.0” area is a young research area, but the period of its emergence has already passed (2013). Since 2014, when only 35 papers were published in the WoS database, there has been a very intense growth of interest in this topic (issues). In 2017, the number of articles was 920, and since 2019, it has already exceeded the number of two thousand—every year.
- For the area “business models and Industry 4.0”, the emergence phase dates back to 2015 (1 publication) and 2016 (11 publications). In 2019, the number of publications in this area increased to 46—this area is now in the final phase of definition.

Based on the Web of Science database, a ranking of scientists according to the number of published scientific papers indexed by this database (but with the number of published papers not less than three) was extracted. Table 2 shows the ranking of five scientists (top five), i.e., with the highest number of papers in a given research area. Within Area I, the most active researchers are from Denmark, Italy, China, England and the Netherlands and have written 183 publications. Within Area II, the most active researchers come from Mexico, Russia, Italy, China and the USA and have published 268 papers in the WoS database. On the other hand, for Area III, it is possible to identify 36 publications that met the defined criteria. Their authors represent Spain, Austria, Italy, Switzerland, Serbia, Germany and Poland. In Area III, no Chinese author was included in the top five list.

Table 2. Top 5 authors (no less than 3 works).

TOP 5	Surname of the Author	Country of Origin of the Author	H-Index	Search Results (Number of Documents)
Area I—Business Models				
I	Lindgren P.	Denmark	6	37
II	Ghezzi A.	Italy	18	34
III	Zhang J.	China	0	30
IV	Bocken NMP.	Netherlands	34	28
IV	Evans S	England	27	28
V	Bouwman H.	Netherlands	21	26
Area II—Industry 4.0				
I	Romero D.	Mexico	19	36
I	Zharinov IO.	Russia	4	36
II	Rauch E.	Italy	17	35
II	Shukalov AV.	Russia	13	35
III	Zakoldaev DA.	Russia	4	34
IV	Leitao P.	No data available	-	31
IV	Li D.	China	10	31
V	Wuest T.	USA	-	30
Area III—Business Models and Industry 4.0				
I	Ganzarain J.	Spain	4	4
I	Ibarra D.	Spain	2	4
I	Muller JM	Austria	8	4
II	Adrodegari F.	Italy	11	3
II	Gebauer H.	Switzerland	32	3
II	Herceg IV.	Serbia	1	3
II	Igartua JL.	Spain	6	3
II	Krcmar H.	Germany	7	3
II	Saccani N.	Italy	22	3
II	Saniuk S.	Poland	12	3
II	Schaefer D.	Switzerland	29	3

Five leading scientific institutions whose researchers published the most scientific papers in each area were selected from the statistics compiled (Table 3). It was found that researchers from these distinguished research centers published a total of 656 papers for Area I, 629 papers for Area II and 25 papers for Area III.

Table 3. Top 5 research centers (no less than 4 works).

TOP 5	Name of the Research Center	Search Results (Number of Documents)
Area I—Business Models		
I	University of California System	145
II	University of London	143
III	Delft University of Technology	129
IV	Polytechnic University of Milan	122
V	University of Cambridge	117
Area II—Industry 4.0		
I	Centre National De La Recherche Scientifique Cnrs	120
I	RWTH Aachen University	120
II	Fraunhofer Gesellschaft	115
III	Polytechnic University of Milan	106
IV	University of Basque Country	89
V	Universidade Do Minho	79
Area III—Business Models and Industry 4.0		
I	Technical University Czestochowa	5
II	Aarhus University	4
II	Centre National De La Recherche Scientifique	4
II	Linköping University	4
II	Mondragon Unibertsitatea	4
II	University of Zielona Gora	4

The Web of Science database allows for a detailed insight into the types of scientific areas in the selected scientific works. For each field of analysis, five fields of science which the individual publications are most often classified as belonging to are indicated. In-depth analysis indicated that the subject matter under examination is characterized by a multidisciplinary specificity. Such an approach allows for a comprehensive approach to research. A wide range of studies also characterized the analyzed areas; they drew knowledge about research methodologies, methods and tools from many sciences. Therefore, the studied areas cannot be explicitly subordinated to any of the sciences according to the classification of sciences adopted by the OECD. No scientific publication or scientific journal was found in the database with a “one-dimensional” character. The identified scientific papers were assigned to individual fields of science. This list is very diverse. However, it can be noted that Area I is primarily classified within the management and economic sciences (although business models originate from informatics), while Area II can be called “purely technical”, and Area III is a combination of the so-called “soft” and engineering and technical sciences. In order to verify the obtained results, the sources in which the researchers published the most works from the examined areas were also analyzed; similar to the previous categories, a list of the five most popular categories was compiled in three areas (Table 4). The analysis of the source titles of the publications confirmed that the studied topic has a multidisciplinary specificity (Table 5).

Table 4. Top 5 Web of Science categories.

TOP 5	Category Name	Search Results (Number of Documents)
Area I—Business Models		
I	Management	3443
II	Business	3300
III	Computer Science Information System	1799
IV	Engineering Electrical Electronic	1458
V	Computer Science Theory Methods	1217
Area II—Industry 4.0		
I	Engineering Electrical Electronic	1841
II	Engineering Manufacturing	1555
III	Engineering Industrial	1549
IV	Computer Science Theory Methods	1340
V	Automation Control Systems	1288
Area III—Business Models and Industry 4.0		
I	Management	42
II	Business	41
III	Green Sustainable Science Technology	31
IV	Engineering Industrial	29
V	Environmental Sciences	27

Table 5. Top 5 source titles (no less than 4 works).

TOP 5	Source Titles	Search Results (Number of Documents)
Area I—Business Models		
I	<i>Sustainability</i> —Journal	430
II	<i>Journal of Cleaner Production</i> —Journal	285
III	<i>Lecture Notes in Computer Science</i> —Journal	186
IV	<i>Procedia CIRP</i>	148
V	<i>Lecture Notes in Business Information Processing</i> —Journal	113
Area II—Industry 4.0		
I	<i>Ifac Papersonline</i> —Journal	246
II	<i>Sustainability</i> —Journal	245
III	<i>Procedia Manufacturing</i> —Journal	219
IV	IFIP Advances in Information and Communication Technology—Book Series	208
V	<i>IEEE Access</i>	197
Area III—Business Models and Industry 4.0		
I	<i>Sustainability</i> —Journal	22
II	<i>Technological Forecasting and Social Change</i> —Journal	7
III	IFIP Advances in Production Systems (Conference)	5
III	<i>Procedia CIRP</i>	5
IV	Education Excellence and Innovation Management: A 2025 Vision To Sustain Economic Development During Global Challenges (Conference)	4
IV	IEEE International Conference on Engineering, Technology and Innovation (Ice/Itmc) (Conference)	4
IV	<i>Journal of Cleaner Production</i> —Journal	4

For each study area, we searched for papers distinguished by the “Highly Cited Paper” designation in the Web of Science database. For Area I, 169 such publications were determined in the database. For Area II, 197 publications were selected, while for Area III, 13 publications were distinguished. However, it should be remembered that the substantive quality of the work may determine a high citation index, the author’s authority, open access to the publication, the time at which the publication was published, etc. The lists of the five publications with the highest citation index are as follows. For Area I—Business Models, the following publications have the highest citation index:

1. Teece D.J. (2010) Business Models, Business Strategy and Innovation. *Long Range Planning* 43:2–3, pp. 172–194. This publication has been quoted 2504 times; its aim is to understand the importance of business models and explore their links with business strategies, innovation management and economic theory.
2. Amit R., Zott C. (2001) Value creation in e-business. *Strategic Management Journal*, 22(6–7), pp. 493–520. This publication has been quoted 2014 times. The publication describes business models as the design of transactional content, structure and governance to create value by exploiting business opportunities.
3. Zott C., Amit R., Massa L. (2011) The Business Model: Recent Developments and Future Research. *Journal of Management* 37:4, pp. 1019–1042. This publication has been quoted 1673 times to explain the concept of business models for banks and find a way to identify digital business models of banks.
4. Chesbrough H., Rosenbloom, S. (2002) The role of the business model in capturing value from innovation: evidence from Xerox Corporation’s technology spin-off companies. *Industrial and corporate change*, 11(3), 529–555. This publication has been quoted 1672 times. This paper explores the role of the business model in capturing value from early-stage technology.
5. Rochet J.-Ch., Tirole J. (2003) Platform Competition in Two-Sided Markets. *Journal of the European Economic Association*, 1(4), pp. 990–1029, <https://doi.org/10.1162/154247603322493212> (accessed on 23 November 2021). This publication has been quoted 1531 times. This paper builds a model of platform competition with two-sided markets.

For Area II—Industry 4.0, the following publications have the highest citation index:

1. Lasi H., Fettke P., Kemper H.G., Feld T., Hoffmann M. (2014). Industry 4.0. *Business & information systems engineering*, 6(4), pp. 239–242. This publication has been quoted 1230 times; its aim is to describe Industry 4.0.
2. Xu L.D., Xu E.L., Li L. (2018) Industry 4.0: state of the art and future trends, *International Journal of Production Research*, 56:8, pp. 2941–2962, <https://doi.org/10.1080/00207543.2018.1444806> (accessed on 23 November 2021). This publication has been quoted 750 times. This paper reviews the state of the art of Industry 4.0 as it relates to industries.
3. Lee J., Hung-An K., Shanhu Y., Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment. *Procedia CRIP*, <https://doi.org/10.1016/j.procir.2014.02.001> (accessed on 23 November 2021). This publication has been quoted 747 times. The purpose of this paper is to discuss the trends of transformation of manufacturing services in a big data environment and the readiness of intelligent predictive computing tools to manage big data to achieve transparency and productivity in this way.
4. Zhong R., Xu X., Klotz E., Newman S. (2017). Intelligent manufacturing in the context of industry 4.0: a review. *Engineering*, 3(5), pp. 616–630. This publication has been quoted 672 times. This article provides a comprehensive overview of related Industry 4.0 topics such as smart manufacturing, Internet of Things (IoT)-based manufacturing and cloud-based manufacturing.
5. Yongxin L., Deschamps F., Rocha E., Ramos L. (2017) Past, present and future of Industry 4.0—a systematic literature review and research agenda proposal, *International Journal of Production Research*, 55:12, pp. 3609–3629, <https://doi.org/10.1080/00207543.2017.1308576> (accessed on 23 November 2021). This publication has been quoted 602 times. The purpose of this article is to outline research trends in Industry 4.0.

For Area III—Business Models and Industry 4.0, the following publications have the highest citation index:

1. Moeuf A., Pellerin R., Lamouri S., Tamayo-Giraldo S., Barbaray R. (2018) The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research* 56:3, pp. 1118–1136. This publication has been quoted 250 times; its purpose is to provide a literature review of existing applied research, covering various issues of Industry 4.0 in relation to SMEs.
2. Muller J.M., Buliga O., Voigt K.L. (2018) Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change* 132, pp. 2–17. This publication has been quoted 249 times. Its purpose is to analyze how Industry 4.0 triggers changes in the business models of manufacturing SMEs (small and medium-sized enterprises) by conducting qualitative research on a sample of 68 German SMEs from 3 industries (automotive suppliers, mechanical engineering and factories, as well as electrical engineering and ICT).
3. Nascimento D.L.M., Alencastro V., Quelhas O.L.G., Caiado R.G.G., Garza-Reyes J.A., Rocha-Lona L. Tortorella G. (2019) Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal”, *Journal of Manufacturing Technology Management*, 30(3), pp. 607–627. <https://doi.org/10.1108/JMTM-03-2018-0071> (accessed on 23 November 2021). This publication has been quoted 152 times. This article aims to explore how rising technologies from Industry 4.0 can be integrated with circular economy (CE) practices to establish a business model that reuses and recycles wasted material such as scrap metal or e-waste.
4. Frank A.G., Mendes G.H.S., Ayala N.F., Ghezzi A. (2019) Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change* 148, pp. 341–351. This publication has been quoted 148 times. It aims to show the basis for the growing research on the interface between service and Industry 4.0 because servicing and Industry 4.0 are considered to be two of the latest trends transforming industrial enterprises.
5. Ghobakhloo M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of cleaner production*, 252, 119869. This publication has been quoted 129 times. This paper aims to add to the sustainability literature by systematically identifying sustainability functions in Industry 4.0.

Based on the conducted research, international research trends for 1 January 1996 to 31 October 2021 were identified based on scientific publications included in the international indexing database Web of Science. Analyzing the created semantic map (Figure 6), it is possible to identify the non-linear development of concepts and rapid changes in thinking and conducting scientific research. The purpose of visualizing the knowledge of business models and Industry 4.0 is to ask the following questions:

- (1) How have international research trends evolved from 1 January 1996 to 31 October 2021 (from the areas visualized in Figure 6)?
- (2) What are the key conceptual clusters formed on the historiographic map of scientific publications from 1 January 1996 to 31 October 2021?

The verification of the term network shown in Figure 6 reveals potential links grouped into topics. For the publications identified in the business models and Industry 4.0 area, the terms are divided into three clusters. The red cluster is oriented around companies. Terms such as business model, business model innovation, business model perspective, revenue, finance and waste belong to this cluster. The business process cluster refers to technique, property, algorithm, modeling, model transformation and development process. The third cluster, marked in blue, includes concepts related to the business cycle such as period, rate, effect, increase, parameter and prediction.

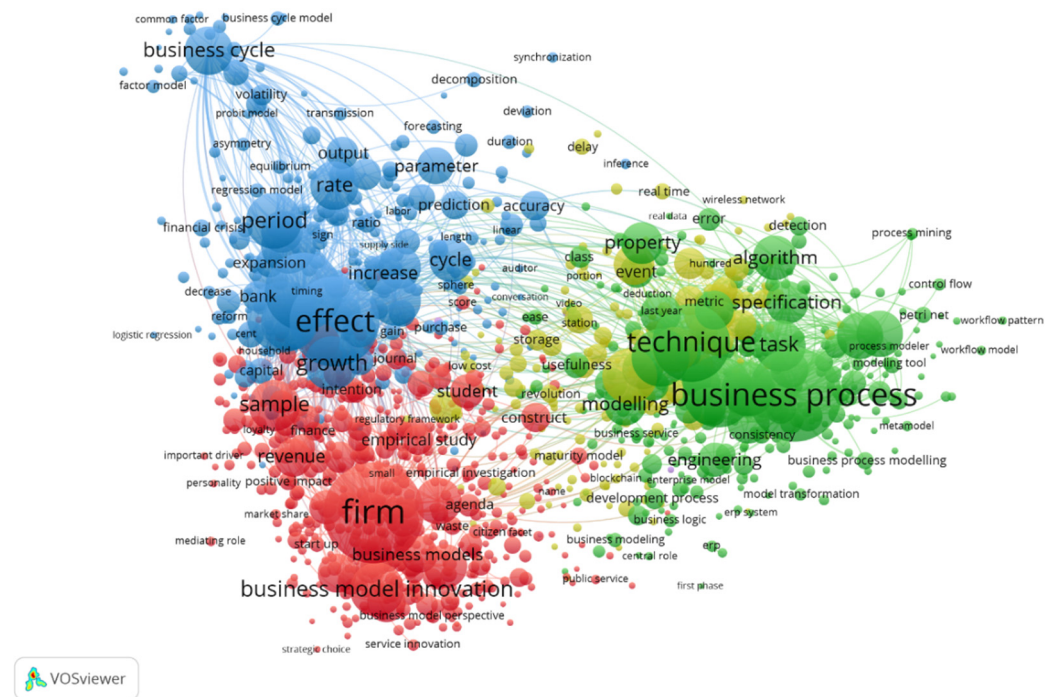


Figure 6. Historiographic map of scientific publications on “business models and Industry 4.0” from 1 January 1996 to 30 October 2021.

5. Discussion

Interestingly, A. Afuah [78] stated that two important theses must be considered to determine the essence of a business model:

Thesis I: An organization using its resources to run a business generates revenue, “offering it to the sector”. It offers the highest value to the client, while being in a position to capture value.

Thesis II: The competitiveness and flexibility of a company are determined by the combined interaction of company-specific factors with sector-specific factors.

The business model can also be understood as the organization’s adoption of methods of increasing and using resources in order to provide its customers with a range of products and services that are worth more than those of its competitors and that, at the same time, ensure the organization’s profitability [79,80]. It is treated as one of the determinants influencing the company’s efficiency. In comparison, B. Nogalski [81] pointed out that the business model is closely related to processes, particularly business processes, and therefore business management. The business model of an enterprise is a concept of how it intends to conduct its business in the environment it identifies with. Its shape, to a certain extent, is a specific configuration of resources, activities and offered products or services, which ensures the creation of value for the customer and the generation of profit for the owners of the enterprise [82].

In the literature, the dominant belief is that building business models is an important management instrument, which is a recipe for achieving competitiveness, flexibility and effective action. However, there is quite a clear research gap concerning the details of the methodology of building such models [83,84].

As a result of the conducted research, common research areas were identified for the scientific works under consideration in the third area (business models and Industry 4.0) of this bibliometric analysis—this area was mainly focused on due to the search for pillars that will form the basis of the architecture of business models of enterprises operating in the era of Industry 4.0. Detailed analysis of the content of the selected publications indicated that the construction of business models in an environment shaped by Industry 4.0 is most often associated with the attributes of Industry 4.0 (Internet of Things, big data, blockchain,

smart factory, machine learning, 3D printing, etc.), cyber-physical collaborative networks, servicing, production personalization, equivalence and talent management. The authors of the published papers in this area formulated the following research questions:

1. How will the innovative business model be structured, especially in the SME sector?
2. How can the business model lead to a sustainable society?
3. Will servitization be a new direction for business models?
4. What will be the social dimension of business models?

The indicated issues were discussed at many international conferences, such as the following:

1. 10th CIRP Conference on Industrial Product-Service Systems (IPS).
2. 11th International Conference on Business Excellence—Strategy, Complexity and Energy in Changing Times.
3. 25th IEEE International Conference on Engineering, Technology and Innovation/25th ICE/IEEE International Technology Management Conference (ITMC).
4. IFIP WG 5.7 International Conference on Advances in Production Management Systems (APMS).
5. 35th International Business Information Management Association Conference (IBIMA).

Dynamic technological development and solutions implemented in modern companies result in a change in management paradigms and the need to build new business models based on maintaining a balance between the development of autonomous (intelligent) technology and remote communication systems and the quality of life, and recognized values in different societies. This is expressed in the creation of new open business models that allow the introduction of open innovations, rapid reorganization of processes and very flexible adjustment of the functioning of companies to new conditions and dynamically changing competitive and common environments. The issue of business models (especially open business models) has a comprehensive character because its scope covers all forms of business activity from the perspective of economic efficiency and non-financial effects of business activity. Intensive development of the digital economy started open business models, where the traditional formulas of providing value propositions are supported or replaced by solutions based on innovative information technologies and open innovations. This approach has a clear impact on new business concepts that translate into a specific open model that provides a strategic and operational basis for reconfiguring products and processes in an enterprise to compete in the market, determined by the rules of the Fourth Industrial Revolution.

Implementation of technological innovations (pillars of Industry 4.0) will bring many benefits to business models. It will enable the creation of a broad spectrum of value, customer orientation and customer needs, production of highly personalized products and monetization of customer knowledge [85]. Additional benefits of digitization can be derived by companies from servitization. Services can bring value to customers while becoming a channel for collecting data and information designed to support business feedback [86].

Business models are currently a significant area of scientific research exploration related to the search for ways to better understand their very essence and the ecosystems they shape. An in-depth analysis of the publications contained in the Web of Science database allowed defining current research areas in the field of business models in the Fourth Industrial Revolution. Using the filter “Business Model” AND “Industry 4.0”, key words/research areas related to this topic were identified and presented in the form of a cluster (Figure 7).

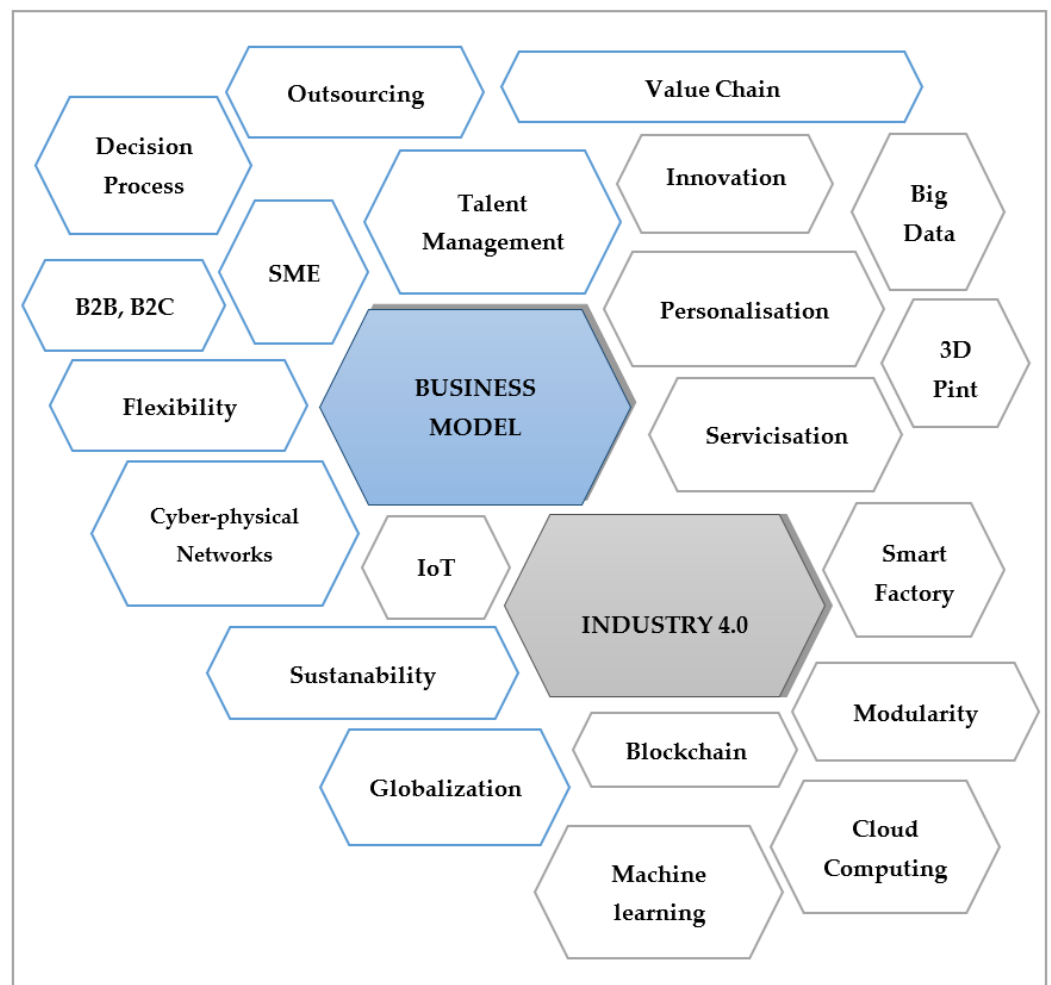


Figure 7. Pillar cluster of business models of enterprises in the Industry 4.0 era. Source: own elaboration.

Directly related to business models according to the identified keywords are the terms value chain, outsourcing, decision making, talent management, SMEs, B2B, B2C, flexibility, cyber-physical networks, sustainability and globalization. The keywords most frequently related to Industry 4.0 were as follows: innovation, big data, personalization, servicing, smart factory, modularity, blockchain, machine learning, cloud computing. These pillars will be the foundation of open business models that make extensive use of open innovation. The modern technology of Industry 4.0 will facilitate knowledge sharing, leveraging the experience of business partners and reaping the benefits of innovation.

However, a growing number of new tools and technologies are still underutilized in the creation of new business models, according to a study by Moewuf et al. This is most likely due to high investment costs [87].

6. Conclusions

This bibliometric analysis of the world's scientific literature in the area of the business model and Industry 4.0 concepts is one of the first of its kind. It attempted to rationalize and systematize the existing scientific knowledge on the concept of business models in the Fourth Industrial Revolution. To this end, various quantitative bibliometric analyses were carried out. The software tools of the Web of Science database were used, which allowed presenting the flow of knowledge over time. The analysis allowed showing the reconstruction of the effects of scientific productivity in the studied areas over time. It was found that most of the publications contained in the Web of Science database concerned Area I—Business Models. This is because this area had the longest research period (from 1 January 1996 to 31 October 2021). The next set of publications in terms of

number of publications included Area II—Industry 4.0, and the smallest set concerned Area III—Business Models and Industry 4.0. Even if the same analysis period, i.e., 1 January 1996 to 31 October 2021, were applied to all three segments, significant changes in the results would not be achieved because both concepts of “Industry 4.0” and business models in the Fourth Industrial Revolution are new concepts.

The conducted research showed a multidisciplinary character of the business model concept in the era of Industry 4.0 implementation. In this way, it was possible to obtain an interesting picture of knowledge from the studied areas. As a result, it can be concluded that business models in the era of the Fourth Industrial Revolution will be built on the pillars of business management and the technical area. The pillars of management will be decision making, outsourcing, value chains, talent management, SMEs, B2B, B2C, flexibility, cyber-physical networks, sustainable development and globalization. The pillars will be innovation, personalization, big data, 3D printing, services, IoT, smart factories, modularity, blockchains, machine learning and cloud computing in the technical field. In the Fourth Industrial Revolution, the concept of open business models is gradually being built using Industry 4.0 pillars to achieve a modern form of management capable of meeting the challenges of a turbulent, competitive and technologically advanced environment, creating an open business model based on innovation, which are the pillars of Industry 4.0. In an open business model using the technological solutions of Industry 4.0, it will be easy to use open innovation, provide access to knowledge and reduce the cost of technology and other new solutions.

This study’s main limitation is based on the number of citations and the popularity of publications, which cannot determine the actual contribution of scientific work in the areas studied. The choice of the Web of Science database, which, despite being an extensive interdisciplinary and international platform, covers only a fraction of scientific publications available worldwide, is one limitation. The fact that the “St. Matthew’s effect” is used in science may also be a criticism, showing a certain dependence. That is, researchers who are more respected in the community and are therefore often cited maintain more citations because their scientific publications are perceived as reliable and reputable.

The analysis of the concept of building models is an essential aspect of the theoretical treatment of business modeling, which is part of strategic management. Researchers’ interest in business models and Industry 4.0 is constantly growing. Theoretically, this study contributes to identifying the current state of knowledge about the concept of business models in the era of the Fourth Industrial Revolution by analyzing the evolution of the state of knowledge and trends. The results can be an important voice in the discussion on the subject under consideration in both technical and economic sciences. In the future, this study may be extended to include an analysis of the strength of the impact of the identified pillars on the architecture of open business models of enterprises operating in the era of Industry 4.0. As the directions of development of open business models and Industry 4.0 are unknown, it will be worthwhile to examine which of the identified pillars will even become megatrends. An in-depth analysis of how Industry 4.0 technology affects the use of open innovation in open business models may also be an interesting direction for future research.

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