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Barno Kulzhambekova
PhD Student (Economics),
Junior Researcher,
Institute for Digital Economy Research;
Karaganda Buketov University
28 Universitetskaya Str., Karaganda, 100000,
Republic of Kazakhstan
birnoshik@mail.ru
ORCID ID:
https://orcid.org/0000-0001-5178-9361

Larissa Tashenova
PhD (Economics),
Director, Institute for Digital Economy Research;
Associate Professor of the Marketing Department,
Karaganda Buketov University
28 Universitetskaya Str., Karaganda, 100000,
Republic of Kazakhstan
larisatash_88@mail.ru
ORCID ID:
https://orcid.org/0000-0001-5022-0421

Dinara Mamrayeva
PhD (Economics),
Professor, Leading Researcher,
Institute for Digital Economy Research;
Head, Marketing Department,
Karaganda Buketov University
28 Universitetskaya Str., Karaganda, 100000,
Republic of Kazakhstan
dina2307@mail.ru
ORCID ID:
https://orcid.org/0000-0001-8508-7317

Theoretical and practical approach to the essential characteristics and structure of digital ecosystems of industrial enterprises

Abstract
Our scientific article is devoted to the study of the essential characteristics and structure of digital ecosystems of industrial enterprises based on the applied theoretical and practical approach. In particular, the author's definitions of the concepts «digital platform» and «digital ecosystem of an industrial enterprise» were given, the distinctive features and advantages of using digital ecosystems, including within the framework of industrial production, were highlighted, the conceptual structure of the digital ecosystem of an industrial enterprise was developed and presented, the examples of practical implementation of digital ecosystems at industrial enterprises in Kazakhstan and neighbouring countries were considered.
We also carried out a scientometric analysis of publications based on the using of materials from the Web of Knowledge database (Web of Science Core Collection) for 1992-2024 using the capabilities of the VOSviewer software product to build thematic frames in the context of three search queries: 1. ««digital ecosystem» and «industry»»; 2. ««digital platform» and «digital transformation»»; 3. ««Digital transformation» and «Industry 4.0»». The final sample within each of the search formulas was: 1859, 3259 and 689 publications, respectively.
The article has developed a comprehensive and adaptive proprietary methodology for conducting scientometric analysis (created taking into account PRISMA recommendations, ensuring validation of the research procedure used in the research), including both the main stages of obtaining a data array and their subsequent analysis based on the specialized software product VOSviewer with the construction of the final frame clusters according to the following criteria: Co-Authorship Analysis, Co-Occurrence Analysis.
Keywords: Digital Ecosystem; Platform Economy; Industry 4.0; Digital Economy; Industrial Enterprise; Scientometric Analysis; Vosviewer
JEL Classification: F6; L6; M21; O14; O25; O32; Q55
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Кульжамбекова Б. Ш.
докторант освітньої програми «Економіка»;
молодший науковий співробітник, Інститут досліджень цифрової економіки,
Карагандинський університет імені академіка Є. А. Букетова, Караганда, Республіка Казахстан
Ташенова Л. В.
кандидат економічних наук, директор,
Інститут досліджень цифрової економіки;
асоційований професор кафедри маркетингу,
Карагандинський університет імені академіка Є. А. Букетова, Караганда, Республіка Казахстан
Мамраєва Д. Г.
кандидат економічних наук, професор,
провідний науковий співробітник;
Інститут досліджень цифрової економіки;
завідувач, кафедра маркетингу,
Карагандинський університет імені академіка Є. А. Букетова, Караганда, Республіка Казахстан

Теоретико-практичний підхід до сутнісних характеристик і структури цифрових екосистем промислових підприємств

Анотація
Дана наукова стаття присвячена дослідженню сутнісних характеристик та структури цифрових екосистем промислових підприємств на основі теоретико-практичного підходу, що застосовується. Зокрема, були надані авторські визначення поняттям «цифрова платформа» та «цифрова екосистема промислового підприємства», виділено відмінні риси й переваги застосування цифрових екосистем, у тому числі в рамках промислового виробництва, розроблено та представлено концептуальну структуру цифрової екосистеми промислового підприємства, розглянуто приклади практичного впровадження цифрових екосистем на промислових підприємствах Казахстану та сусідніх держав.
У роботі нами також було проведено наукометричний аналіз публікацій на основі використання матеріалів бази даних Web of Knowledge (Web of Science Core Collection) за 1992-2024 роки з використанням можливостей програмного продукту VOSviewer для побудови тематичних кадрів у розрізі трьох пошукових запитів: 1. «ecosystem» та «industry»»; 2. «digital platform» та «digital transformation»; 3. «digital transformation» та «Industry 4.0». Підсумкова вибірка в межах кожної з пошукових формул становила: 1859, 3259 і 689 публікацій відповідно.
У статті розроблено комплексну й адаптивну авторську методику проведення наукометричного аналізу (створена з урахуванням рекомендацій PRISMA, що забезпечують валідацію дослідницької процедури, використаної в дослідженні), що мвстить як основні етапи отримання масиву даних, так і їх подальший аналіз на базі спеціалізованого програмного продукту VOSviewer з побудовою підсумкових кластерів-фреймів за такими критеріями: Co-Authorship Analysis, Co-Occurrence Analysis.
Ключові слова: цифрова екосистема; платформна економіка; індустрія 4.0; цифрова економіка; промислове підприємство; наукометричний аналіз; VOSviewer.

1. Introduction

With the onset of the era of the digital economy and innovative development of economic systems through the widespread application of artificial intelligence and information and communication technologies, the international academic community is actively studying the issues of digital transformation of the economy.

The World Economic Forum experts emphasize the significance of digital transformation for the global economy, estimating it at USD 100 trillion by 2025, as well as potential 20% reduction in pollutant emissions through the scaling of digital solutions in industries that are difficult to reduce emissions from, including: steelmaking, cement, chemicals, aviation, cargo transportation by land, and maritime intercontinental transport (World Economic Forum, 2023).

According to the World Bank's definition, in the digital economy, the advancement and implementation of digital technologies lead to increased labor productivity and business competitiveness, a reduction in production costs, the creation of new jobs, and a decrease in social inequality. The National Research University «Higher School of Economics» defines the digital economy as «activities related to the creation, distribution, and use of digital technologies and associated products and services» (NRU «Higher School of Economics», 2019).

European and Asian countries, including the USA, the Netherlands, Singapore, Denmark, Switzerland, as well as Korea, Taiwan (China) stand out among countries with well-developed digital economies. According to the World Digital Competitiveness Index (WDCI) in 2023, Figure 1 shows the TOP-10 ranking of leading countries in the use of digital technologies and innovations, contributing to the dynamic development of their economies in the digital era (IMD World Competitiveness Center, 2023).

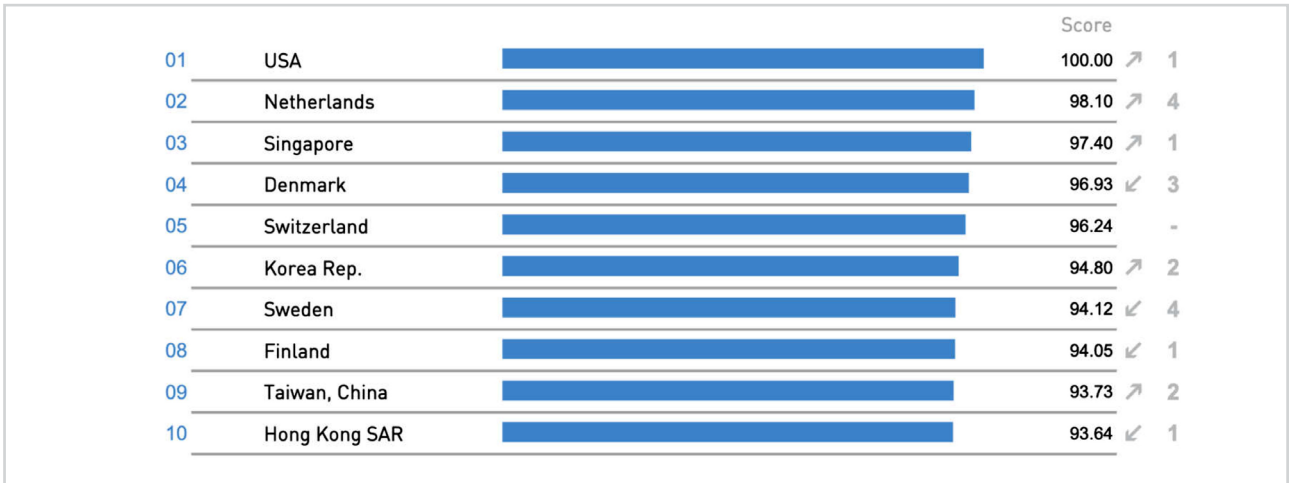

Figure 1:
World Digital Competitiveness Ranking 2023
Source: Compiled on the basis of the IMD World Competitiveness Center

This global competitiveness ranking of the digital economy, conducted for the seventh year by the World Competitiveness Center of the International Institute for Management Development (IMD), evaluates the ability and readiness of 64 countries to adopt and explore digital technologies as a fundamental factor in economic transformations in business, government administration, and society in general.

The following index, «The Digital Economy and Society Index» (DESI), characterizes the level of the digital economy in European Union countries. The four main indicators of this index include the following: the availability of broadband connectivity, its quality and speed, 5G network coverage; the prevalence of digital skills among the population, the number of ICT specialists; the integration of digital technologies (AI, Cloud, Big Data); digital public services for the population and businesses (presence of online trading channels, digitization of the public sector in the country). The TOP-10 countries according to this ranking in 2022, included the following states: Finland, Denmark, the Netherlands, Sweden, Ireland, Malta, Spain, Luxembourg, Estonia, Austria, with the average level across the EU reaching 52% (The European Commission, 2022).

With the rise of various digital technologies and the rapid development of digital economies, a new concept has begun to take shape - the platform economy (Figure 2).

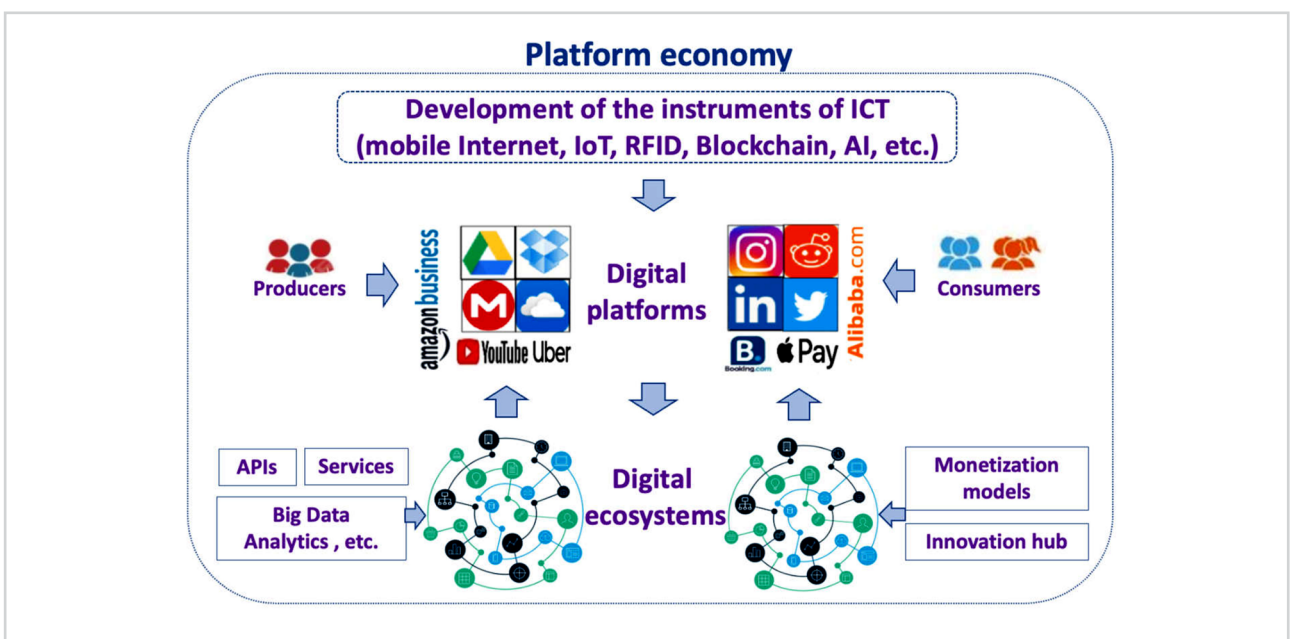

Figure 2:
Platform economy's structure
Source: Compiled by the authors

The platform economy represents an economic system in which digital platforms/unified digital platforms play a central role, serving as a «meeting place» for various participants such as manufacturing companies, consumers, IT product developers, facilitating their efficient interaction, exchange of goods and services, as well as information (Balanova, 2021). This results in more flexible, scalable, and innovative business models.

Customers find it increasingly convenient to make online purchases, driving the shift from physical transactions to digital ones. Successful companies actively leverage digital platforms (DP) to gain advantages from the network effect, thereby providing greater value to an extended user base. A well-chosen digital strategy can help platform companies overcome the constraints imposed by geopolitical borders and foster international collaboration (Madanaguli et al., 2023).

According to M. Jacobides, «the upcoming era of digital platforms provides the opportunity for various types of economic entities (service and manufacturing, small and medium-sized, domestic and foreign) to gain competitive advantages from the processing of digital data» (Jacobides et al., 2018).

During the research of the nature of digital platforms, Evans P.C. identified four types: innovative (Microsoft, Intel, Oracle, SAP), investment-oriented (Softbank, Naspers, Priceline), transactional (PayPal, Yahoo, Tencent, Uber, eBay, Netflix, Airbnb, Baidu, etc.), and integrated (Google, Facebook, Apple, Amazon, Alibaba). It should be mentioned that, in practice, digital platforms often comprise multiple functional characteristics at once (Evans & Gawer, 2016).

In the context of this scientific article, ***digital platforms*** are understood as information systems that combine various elements (markets, companies, communities, and technological systems), aimed at creating value through facilitating direct interaction (communication, information retrieval, making purchases, providing services, intellectual property rights protection, etc.) and conducting transactions among multiple groups of external users (producers, suppliers, developers, consumers).

Digital ecosystems are the result of the evolutionary development and connectivity of digital platforms and digital tools, which are represented as a symbiosis of such interaction.

The concept of an ecosystem in economics was initially proposed by the American scholar James Moore in his work «Predators and prey: a new ecology of competition», presented in the «Harvard Business Review» journal, in which he identified a business ecosystem as an economic community of interconnected organizations and individuals producing goods and services valuable to the consumer, all of which are integral parts of the ecosystem itself. The leader of the ecosystem plays a crucial role, driving the ecosystem community towards shared visions, achieving return on investment, and fulfilling a mutually supportive role (Moore, 1993).

Michael G. Jacobides, in his work «Platforms and Ecosystems: Enabling the Digital Economy», describes digital ecosystems as «interacting organizations with modular architecture, not governed by hierarchical structures, and connected to digital networks» (Jacobides et al., 2019).

Marco Iansiti, a professor at Harvard Business School, and Roy Levien, a scientist - inventor, a laureate of Microsoft award, in their collaborative publication «Strategy as Ecology», describe business ecosystems as a loose network of technology providers, distributors, product and service manufacturers, and other organizations that influence the creation of a company's offerings (Iansiti & Levien, 2004).

Despite being interconnected concepts in the digital business and technological space, digital platforms and ecosystems have distinctive features.

Both digital platforms and digital ecosystems facilitate the development and delivery of digital services, applications, or products.

At the same time, digital platforms contribute to the formation of the technical foundation for applications, whereas digital ecosystems encompass a broader network of interconnected participants collaborating to create value. The primary distinction are found in the scale, ownership, and degree of interdependence among different components of each of these economic categories.

Conversely, it can be observed that digital ecosystems have become an integral part of enterprises across a wide range of economic sectors, including companies of the industrial sector and complex integrated industrial structures, for which issues of effective communication among all participants become particularly relevant in the face of increasing competition and globalization of business.

During the development of an ecosystem, its transition from one state to another is observed under the influence of various factors in the external and internal environment. At the stage of ecosystem emergence, there is a minimal level of collaboration between the new enterprise and ecosystem participants, with a limited number of new resources entering and circulating within the ecosystem (Figure 3).

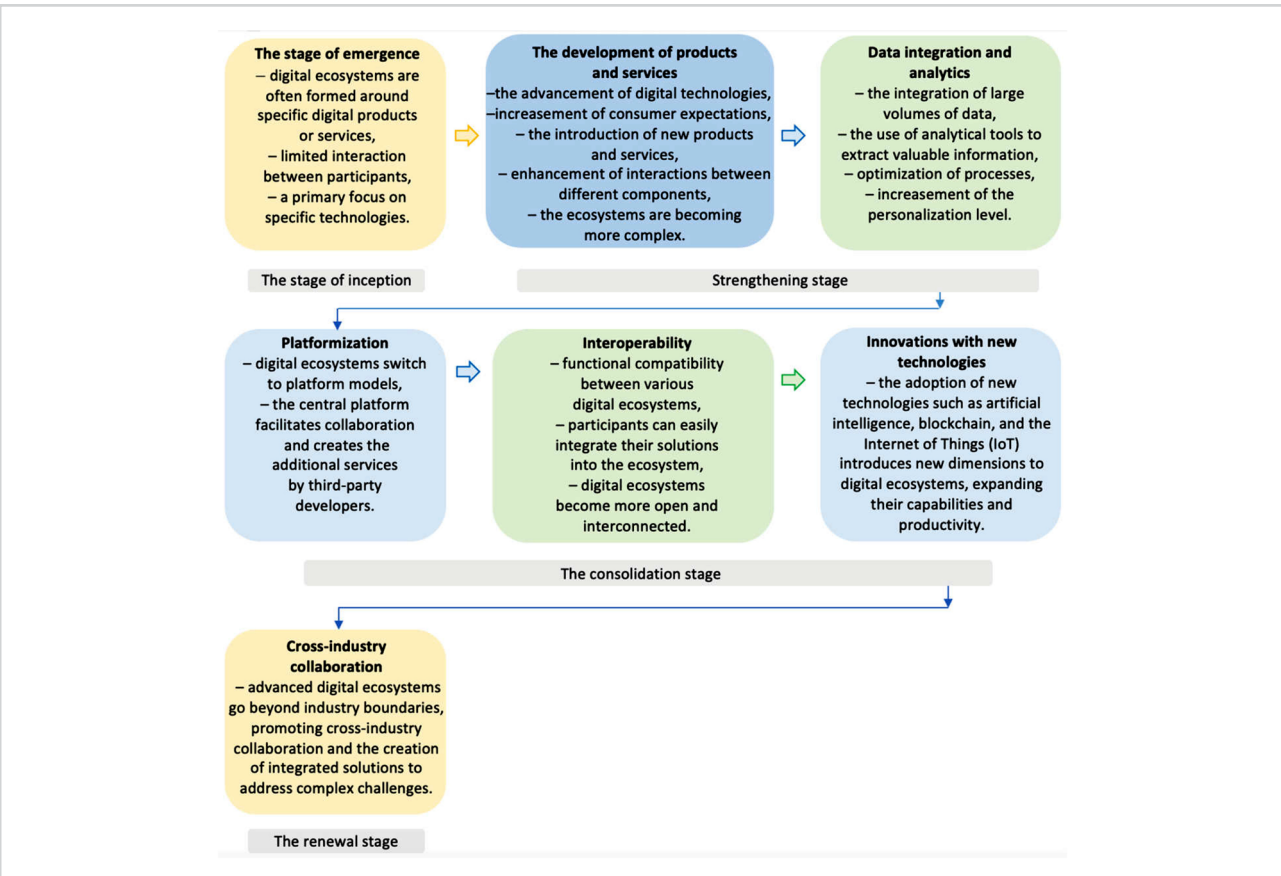

Figure 3:
Evolutionary development of digital ecosystems
Source: Compiled by the authors

Continuous innovative development as well as the ongoing enrichment with new knowledge and technologies play a crucial role in achieving the long-term success of a digital ecosystem and its ability to modernize (Popov et al., 2023).

Based on the conducted research and the study of works by foreign and Russian scientists on the essence of digital ecosystems, we propose the following ***authors' definition of the digital ecosystem of an industrial enterprise***: «The digital ecosystem of an industrial enterprise is an integrated, self-organizing system made up of technological platforms, digital technologies, smart devices, applications, software, and ecosystem participants, which are united for the efficient and flexible support, optimization, and real-time analytics of all aspects of the industrial enterprise's business processes through a management system based on predictive models that assess and forecast the state of resources in manufacturing processes».

In a digital ecosystem, interacting organizations are connected by digital technologies, creating value for the end consumer, platform owner, and all participants. The platform serves as the primary building block of the ecosystem, where participants develop their products and services (Mikhailov, 2022). The digital ecosystem expands the concept of a traditional business ecosystem, emphasizing the crucial role of digital technologies.

According to a study by the international consulting company PwC (PricewaterhouseCoopers, 2018), a digital ecosystem is formed by four critical ecosystem levels: the customer solutions ecosystem, operations ecosystem, technology ecosystem, and personnel ecosystem. The operations ecosystem in a company may be represented by corporate systems, such as ERP and CRM systems. The technology ecosystem enables improvements to be implemented

across the other ecosystem levels. The personnel ecosystem includes HRM systems, time tracking systems, biometric systems, etc. (PwC, 2018).

The conceptual structure represents an interconnected complex of technologies, processes, and interactions aimed at efficient and innovative management of an industrial enterprise in the digital era (Figure 4).

Therefore, it can be concluded that the digital ecosystem is a digital environment in which users are provided with various products/services via platform services, within a unified «seamless» process.

The purpose of this research paper is to investigate the characteristics and structure of digital ecosystems in industrial enterprises.

The primary objectives are defined as follows:

1. studying the key stages of the formation and development of the digital and platform economy;
2. examining the essence and structure of digital platforms and digital ecosystems of industrial enterprises;
3. developing the conceptual structure of an industrial enterprise's digital ecosystem;
4. conducting a scientometric analysis using the proposed adaptive author's methodology in the context of three key queries (««digital ecosystem» and «industry»»; ««digital platform» and «digital transformation»»; ««digital transformation» and «Industry 4.0»») to identify trends within the framework of the scientific issues under study;
5. consideration of examples of implementation and adaptation of digital ecosystems / digital platforms by manufacturing enterprises in Kazakhstan and Russia.

The research questions outlined in this scientific article are as follows:

1. What key research trends can be identified through conducting scientometric analysis across three search queries (1. ««digital ecosystem» and «industry»»; 2. ««digital platform» and «digital transformation»»; 3. ««digital transformation» and «Industry 4.0»») using the Web of Science dataset (RQ1)?
2. What are the features of the implementation and adaptation of digital ecosystems/digital platforms by industrial enterprises of Kazakhstan and Russia (RQ2)?

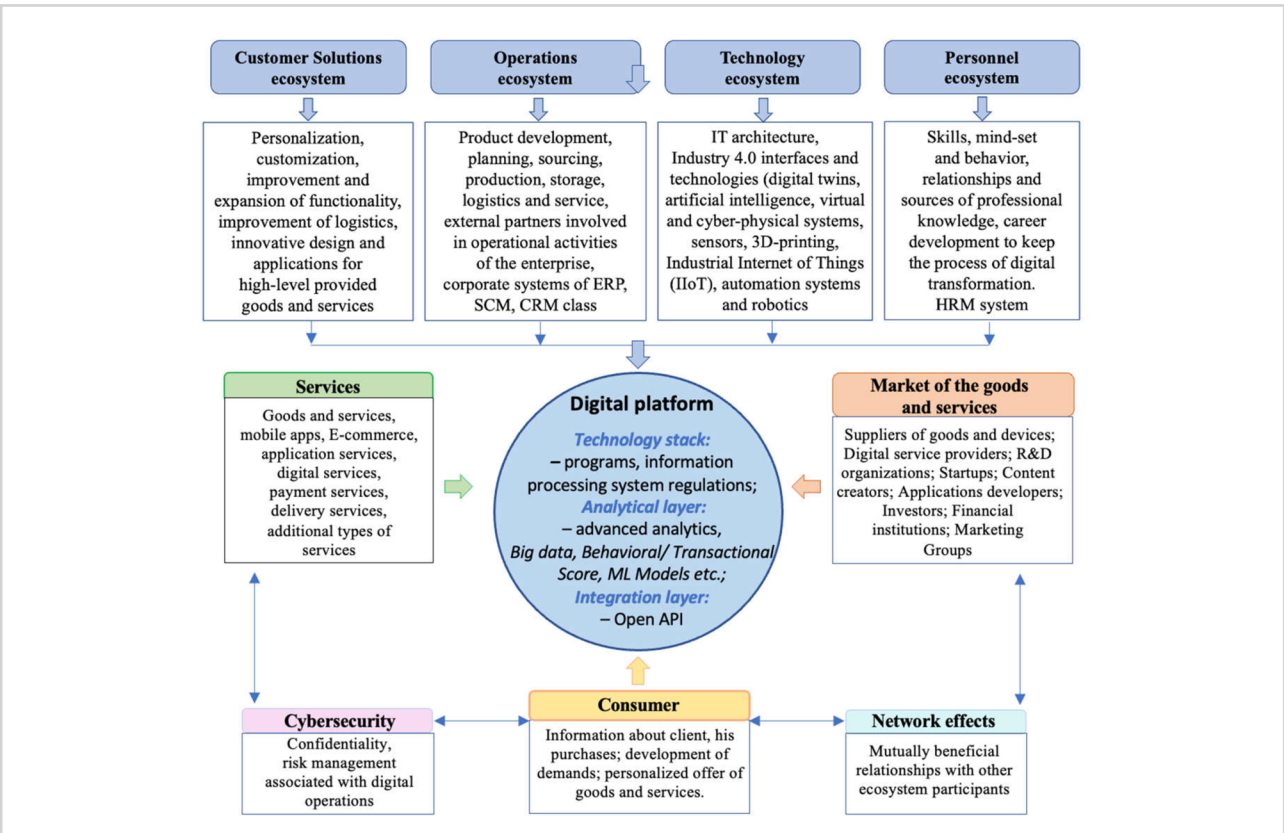

Figure 4:
The conceptual structure of digital ecosystem of an industrial enterprise
Source: Compiled by the authors

2. Brief Literature Review

Digital platforms in industrial manufacturing have formed the foundation for creating industrial digital ecosystems and transforming the way goods are produced (Orlovska, 2020; Ignatova et al., 2020; Cennamo, 2021; Mi & Coffman, 2019; Lin et al., 2022; Akbar & Tracogna, 2022 ; Platonova & Ziyan, 2022).

The questions regarding the formation and development of ecosystems in diverse industrial sectors were examined by a large pool of researchers (Darking & Whitley, 2007; Chae, 2019, Senyo et al., 2019; Tanina et al., 2022; Babkin et al., 2021). Thus, Subramaniam M. in the publication «Competing in digital ecosystems» highlights production digital ecosystems, that include product manufacture and sale, customer service supply, as well as consumption ecosystems which evolve based on the consumption of sold goods and provided services (Subramaniam et al., 2019).

Sami Suuronen, along with co-authors in the article «A systematic literature review for digital business ecosystems in the manufacturing industry: Prerequisites, challenges, and benefits», identified the prerequisites, challenges, and benefits of implementing and adapting digital business ecosystems (Suuronen et al., 2022).

Authors N. Bakhtadze and A. Suleykin in the article «Industrial digital ecosystems: Predictive models and architecture development issues», proposed a concept of identification analysis for optimizing the management of industrial digital ecosystems, which involves the use of models, (including predictive ones) of various segments of digital ecosystems to enable real-time management (Bakhtadze & Suleykin, 2021).

The structure, characteristics, and prerequisites for the formation of digital ecosystems in industrial enterprises, as well as various ecosystem strategies and the roles of companies within the ecosystem, are among the trends in contemporary research (Parida et al., 2019; Serdyukov, 2020; Kamalaldin et al., 2021). For example, O. E. Kalenov, in the article «Digital ecosystems of organizations», describes the prerequisites for their emergence, examines the boundaries, structure, and essential elements of the digital ecosystem, illustrates the interaction between the customer and the platform, and explains the mechanism of transforming data into knowledge during their interaction. Furthermore, three approaches to forming digital ecosystems are presented: developing proprietary services, acquiring external ones, and engaging into partnership agreements (Kalenov, 2022).

Within the scope of the platform approach, the authors characterize ecosystems' role in the structure of organizational activities formation (Jacobides et al., 2015; Dong et al., 2007). Camarinha-Matos L. M. and Afsarmanesh H. have defined digital ecosystems as collaborative networks made up of heterogeneous and geographically dispersed entities cooperating via the Internet to achieve common goals (Camarinha-Matos & Afsarmanesh, 2008).

Alessio Cozzolino investigated manufacturers' adaptation systems to the emergence of new ecosystems based on platforms and identified a process characterized by three consecutive phases: (1) selective collaboration, (2) cooperative competition, and (3) selective cooperation (Cozzolino et al., 2021). Komissarova M. A. and Storozhuk I. N. examine the concept and approaches related to the use of digital manufacturing platforms from various perspectives: digital manufacturing platforms, digital platforms as ecosystems, and the digital platform for industrial equipment suppliers and service providers (Komissarova & Storozhuk, 2020).

In a number of scientific publications, the ecosystem is taken into account as a consequence of the shift from traditional participant partnerships to interorganizational cooperation (Kleiner et al., 2020; Volodina, 2021; Pudovkina, 2020; Babkin et al., 2017).

Thus, A. Yu. Nikitaeva highlights the effects resulting from the emergence of ecosystems in the industrial sphere for ecosystem centers (platform owners), participants, consumers of digital industrial ecosystems, as well as the regional economy; identifies a complex of drivers and conditions for the digital transformation of industrial enterprise ecosystems (Nikitayeva et al., 2021).

Participants in the ecosystem can be classified according to the industry, sector or geographical principles (Romanova & Sirotin, 2021; Kulapov et al., 2022; Trofimov et al., 2019; Babkin et al, 2019). In particular, Babkin A. V., Fedorov A. A., Liberman I. V. and Klachek P. M. in their publication «Industry 5.0: concept, formation and development» substantiate that digital platforms and ecosystems that ensure the interaction between different participants are a new subject of economics and governmental influence (Babkin et al., 2021).

In a pool of scientific publications, the principles of operating of business models in the context of digitalization, the impact of cooperation between ecosystem actors on promoting innovation

in companies activities are examined, and related threats are considered (Stolyarova, 2020; Markova & Trapeznikov, 2016; Kukushkin, 2021; Maslennikov et al., 2019; Ayaganova et al., 2019). Particularly, the authors of the paper «Analysis of directions digital technologies are introduced into industrial complex» concluded that the digital transformation of industrial companies requires a systematic view of digitalization at the industry level. In this sense, the state industrial policy encourages industrial growth and import-substituting production (Balashova & Maiorova, 2020).

It is mentioned that upholding specific values is crucial for companies taking part in the digital business-ecosystem (Yun et al., 2020). Alibaba, for example, has successfully evolved from a small business to a giant enterprise, due in part to its strong principles, which include protecting socially vulnerable groups of population, averting environmental disasters, and practicing environmentally responsible business practices (Priyono & Hidayat, 2024). Creating these values is a methodical procedure that follows the company's collaboration with the innovation center (Sassanelli & Terzi, 2022; Crupi et al., 2020).

Thus, digital ecosystems, acting as innovative hubs, become a new way of providing consumers with complementary goods and services offered by a multitude of collaborating and competing companies.

Overall, the analysis of scientific literature has revealed a shift in the paradigm of organizing industrial activities towards the involvement of third parties - distributed digital ecosystems and stronger digital partnerships, since this is advantageous from a strategic perspective, allowing companies to stay competitive in the face of innovations driven by digital technologies and the rapid transformation of entire industries.

Due to the lack of unified approaches among researchers in understanding the nature, structure, and characteristics of digital ecosystems in general, and specifically regarding the features of their adaptation in industrial production, a scientific literature analysis was conducted, using a dataset from the Web of Science database, allowing for the identification of common research directions within the scope of the discussed scientific issue.

3. Methodology and Methods

The scientific article employed a ***theoretical-practical approach (TPA)***, combining theoretical concepts with the potential for practical application. This approach allows for a comprehensive examination of the essential characteristics and structure of digital ecosystems in industrial enterprises, as well as an investigation of the practical opportunities for their adaptation and applicability in company operations.

The distinction of the TPA from others (such as comprehensive or theoretical-methodological approaches) lies in its emphasis on bringing together theoretical and practical components without their complete separation.

The following methods were applied: ***general scientific research methods***, including the method of analysis and synthesis used in studying approaches to the concept of «digital ecosystem», ***structural-functional and generalization methods*** in researching characteristics of digital ecosystems and the conceptual structure of the «digital ecosystem of an industrial enterprise», ***case study method*** in examining practical examples of digital ecosystems implementation of by industrial companies, as well as ***specialized***, including ***method of content analysis*** and ***bibliometric analysis*** of publications, also ***the method of graphical construction of frames*** using the VOSviewer program.

The research data was gathered by analyzing published works presented in the bibliometric database Web of Science Core Collection, which includes the following indices: Science Citation Index Expanded (Sci-Expanded); the Social Science Citation Index (SSCI); the Arts and Humanities Citation Index (AHCI); the Conference Proceedings Citation Index - Science (CPCI); the Conference Proceedings Citation Index - Social Science and Humanities (CPCI-SSH); the Book Citation Index - Science (BCI-S); the Book Citation Index - Social Science and Humanities (BKCI-SSH); the Emerging Sources Citation Index (ESCI).

The search formulas are as follows:

1st Search = All fields: «digital ecosystem» and «industry»;
2nd Search = All fields: «digital platforms» and «digital transformation»;
3rd Search = All fields: «digital transformation» and «industry 4.0».

Figure 5 displays the author's research methodology, consisting of seven primary steps, built upon PRISMA guidelines, which were used to validate the research procedure applied to the study.

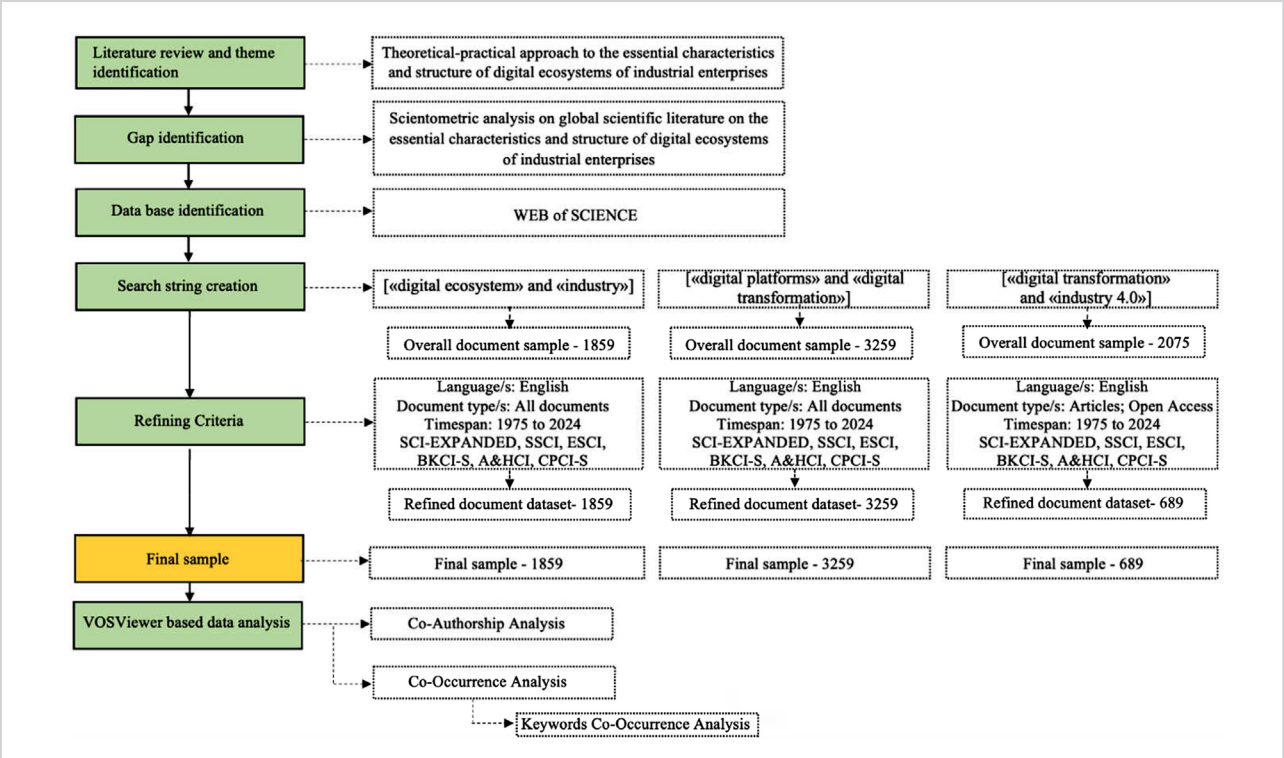

Figure 5:
Scientometric analysis methodology
Source: Compiled by the authors

Within the framework of conducting the 1 - 3 search queries, 1859, 3259, and 689 publications were obtained, respectively, which were subsequently used for bibliometric analysis using the VOSviewer software (version 1.6.20) based on the following criteria: «Co-occurrence Analysis (Keywords Co-occurrence Analysis)», «Co-Authorship Analysis». It is also noteworthy that the initially obtained three sets of publications were analyzed using the features of the webofknowledge.com platform (Clarivate Analytics) - the «Analyze Results» section.

4. Results

4.1. Results of scientometric analysis (RQ1)

4.1.1. General characteristics of search results ««digital ecosystem» and «industry»» in the Web of Knowledge database (Clarivate Analytics) and results of scientometric analysis in VOSviewer.

According to the search query «digital ecosystem» and «industry», the main dataset comprised 1859 publications, with 33% of them falling into the WoS categories: «Management» - 298 (16.05%), «Business» - 239 (12.87%), and «Economics» - 74 (3.98%), which indicates a high level of interest among researchers in the themes of management and business organization in the context of digital transformations, the importance of studying and developing effective management strategies for digital ecosystems across various industries, including the industrial sector.

The third position is held by the category «Computer Science Information Systems», which includes 237 publications (12.75%), addressing issues related to the development and application of information systems to ensure the efficient operation of manufacturing enterprises.

The distribution of publications by country is as follows: the United States - 229 (12.33%), China - 216 (11.69%), England - 187 (10.07%), Germany - 168 (9.05%), and Italy - 163 articles (8.78%). The key period of publications for this search query spans from 2003 to 2024, with the majority of works published between 2019 and 2023 (78%). Additionally, notable researchers have extensive contributions focused on studying the specificities of application digital ecosystems in industry (Table 1): their works address conceptual aspects of digital ecosystem development, encompassing analyses of their application across various economic sectors,

studying business models of digital servitization in ecosystems, and promoting sustainable intelligent production.

As a method of data analysis using the «VOSviewer» software, the «Co-occurrence: Keywords» was selected, which groups keywords into thematic clusters based on the frequency of their occurrence (Figure 6).

The first - the largest cluster - «Innovation» (blue), includes publications focused on various aspects of innovation, ranging from enterprise strategies in implementing innovative approaches to

Table 1:
TOP - 5 scientists with the largest number of publications in the field of «Digital ecosystem» and «Industry»

Name of the scientist	Number of publications	H-Index (WoS)	University	Most cited article(s) by subject / number of citation
Parida, Vinit	12	47	Lulea University of Technology	Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., & Baines, T. (2019). Digital servitization business models in ecosystems: A theory of the firm. Journal of Business Research, 104, 380-392 / 331 citations.
Krcmar, Helmut	8	30	Technical University of Munich	Weking, J., Stöcker, M., Kowalkiewicz, M., Böhm, M., & Krcmar, H. (2020). Leveraging industry 4.0 – A business model pattern framework. International Journal of Production Economics, 225, 107588 /103 citations.
Liu, Yang	8	34	Linköping University	Ma, S., Zhang, Y., Liu, Y., Yang, H., Lv, J., & Ren, S. (2020). Data-driven sustainable intelligent manufacturing based on demand response for energy-intensive industries. Journal of Cleaner Production, 274, 123155 / 92 citations.
Ghezzi, Antonio	6	24	Polytechnic University of Milan	Ghezzi, A. (2019). Digital startups and the adoption and implementation of Lean Startup Approaches: Effectuation, Bricolage and Opportunity Creation in practice. Technological Forecasting and Social Change,146, 945-960 / 85 citations.
Barata, Jose	6	21	Universidade Nova de Lisboa	Nikghadam-Hojjati, S., & Barata, J. (2019). Computational Creativity to Design Cyber-Physical Systems in Industry 4.0. Collaborative Networks and Digital Transformation. PRO-VE 2019. IFIP Advances in Information and Communication Technology, 568, 29-40 / 32 citations.

Source: Compiled by the authors based on the search query «digital ecosystem» and «industry» in WoS

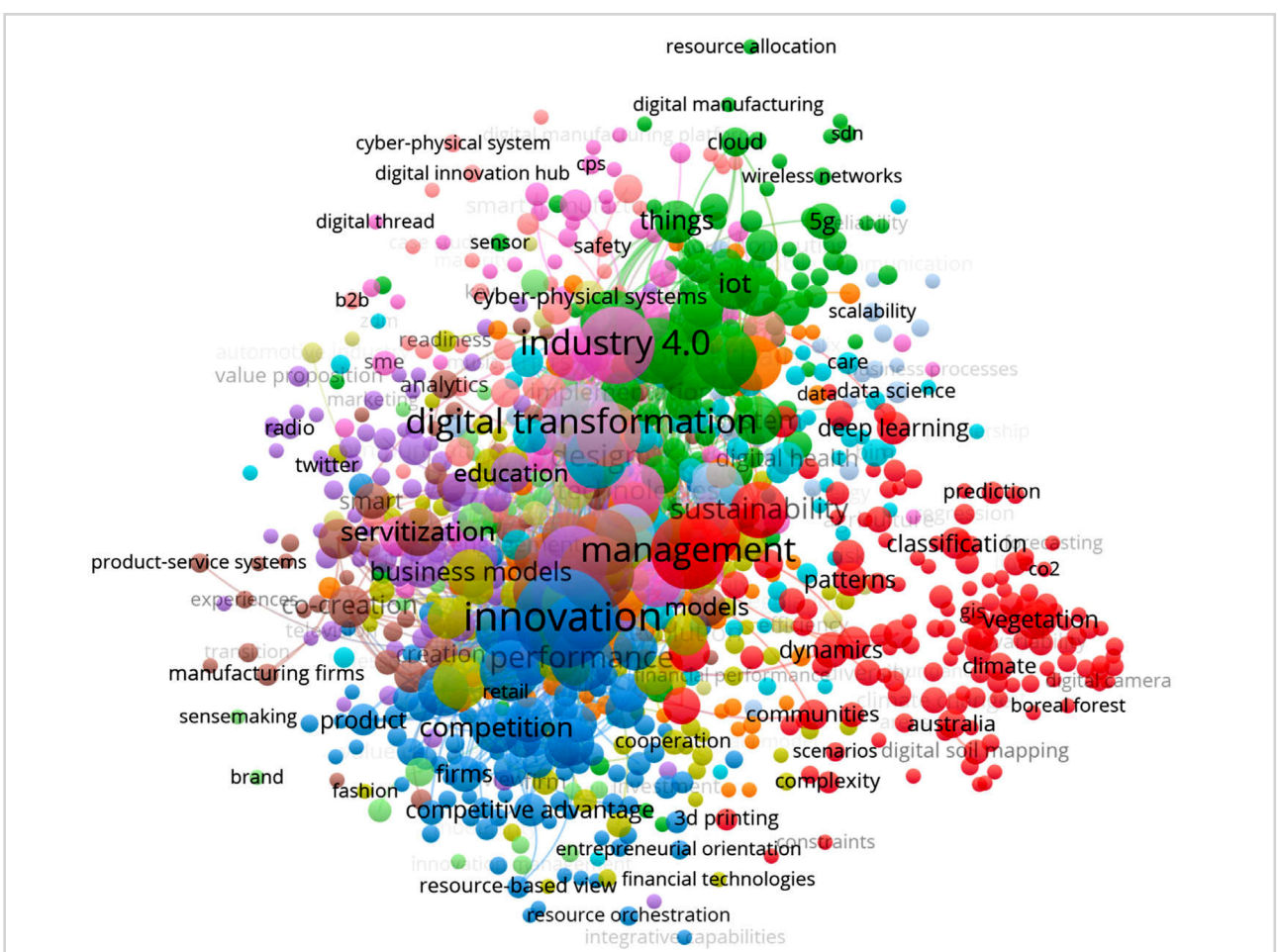

Figure 6:
Results of scientometric analysis for the query «digital ecosystem» and «industry» in terms of the «Co-occurrence: Keywords» criterion
Source: Compiled by the authors

analysis of competition and interactions with entrepreneurial and innovative ecosystems. The examination of business models, startups, and innovative practices underscores the importance of enterprises adapting to rapidly changing market conditions.

The second cluster - «Digital Transformation» (lavender), comprises studies covering various aspects of digital transformation, including the implementation of Industry 4.0 - concept of digital technologies integration into manufacturing processes, and the analysis of the impact of platforms, digital ecosystems, and innovations on the evolution of business models.

«Big Data» (green) - the third cluster obtained from bibliometric analysis - indicates a close connection between key concepts in the field of information technology, such as blockchain, IoT, IIoT, and cloud computing. Furthermore, links to digital manufacturing, digital twins, and 5G indicate big data's impact on the industry development. Security issues and related challenges focus researchers' attention on topics related to the privacy, protection, and ethical aspects of using big data.

The cluster ***«Industry 4.0»*** (lilac) includes publications related to the examination of the impact of climate change on business processes, digital soil mapping, energy efficiency, and additive manufacturing, as well as research in the field of management methods and practices of contributing to sustainable development, the application of energy-efficient practices considering environmental and social aspects in corporate governance.

An additional significant cluster - ***«Ecosystem»*** (purple), serves as a central node for research on various aspects of the interaction of platform ecosystems with educational institutions, which underscores the importance of digital platforms and online applications in education and skill development in the modern digital environment. Links to communication, the media industry, branding strategies, and digital business indicate the role of digital ecosystems in designing new ways to interaction, marketing, and value creation for users.

The ***«Technology»*** cluster (brown), connects the concepts of «digital servitization», «ecosystem», «knowledge», «co-creation», «service innovations», and «manufacturing firms», which reflects technological aspects related to the integration of contemporary technologies in various processes within manufacturing companies, the establishment of digital ecosystems, knowledge management, creativity, service innovations, and collaborative value creation.

4.1.2. General characteristics of search results ««digital platforms» and «digital transformation»» in the Web of Knowledge database (Clarivate Analytics) and results of scientometric analysis in VOSviewer.

According to the search query «digital platforms» and «digital transformation» in Web of Science, the primary dataset consists of 3259 publications, distributed as follows in the Top - 5 countries: China - 529 articles (16.2%), USA - 366 (11.2%), Russia - 326 (10%), Germany - 265 (8.1%), and Spain - 242 (7.4%).

It is worth noting that 2031 articles (62%) are presented in the form of papers published in scientific journals (the most popular publications being «Sustainability», «Communications in Computer and Information Science», «Sensors», «Applied Sciences Basel», «Advances in Intelligent Systems and Computing», «Technological Forecasting and Social Change», «Energies», and others); 1094 (34%) - are conference proceedings («Proceedings of SPIE», «International Scientific Conference Digital Transformation on Manufacturing Infrastructure and Service»), the remaining works - consist of book chapters and editorial materials in journals such as «Lecture Notes In Business Information Processing», «Lecture Notes In Computer Science», «Aebmr Advances In Economics, Business, And Management Research», and «Smart Innovation Systems and Technologies».

The analysis revealed that 35% of publications within this search query are related to computer science, information systems, artificial intelligence, and multidisciplinary applications, confirming the fundamental role of computer science in studying digital platforms and the digital transformation of processes, including in industrial manufacturing.

Approximately 27% of the works were discovered in management, business, and economics categories, demonstrating the importance of study in these fields not only for technological innovations but also for comprehending the impact of digital transformations on management, society, and business.

According to WoS platform data, the leading organizations funding research in the field of «digital platforms» and «digital transformation» include the National Natural Science Foundation of

China, the European Union, the Spanish Government, and the Russian Foundation for Basic Research (RFBR); among the top universities publishing the highest number of articles on the research of digital platforms and key directions of digital transformation across economic sectors are:

- the Russian Academy of Sciences;
- the University of London;
- the Chinese Academy of Sciences;
- Peter the Great St.Petersburg Polytechnic University.

In general, the analysis revealed that researchers' works cover aspects of creating digital platforms based on blockchain technology, studying sustainable business models based on network platforms, digital twins, and include analyses of their application experience in various manufacturing industries.

Figure 7 represents the results of the conducted bibliometric analysis based on the «Co-occurrence: Keywords» criterion, enabling the identification of 15 clusters, which encompass issues related not only to digital transformation and digital platforms directly, but also to aspects associated with the application of social media in the digital environment, the development of the digital economy in the context of Industry 4.0, the potential for creating value chains through the creation of more efficient management and communication conditions, as well as the peculiarities of digital adaptation of companies in pandemic and post-pandemic periods.

Figure 8 displays the connectivity of researcher publications in terms of research institutions within the search terms ««digital platform» and «digital transformation»».

Thus, independent clusters consist of works from the Russian Academy of Sciences, the Chinese Academy of Sciences, the University of Cambridge, the University of Oxford, the Technical University of Munich, the Bucharest Academy of Economic Studies, the University of Amsterdam, and others, that are interconnected through co-authorship, emphasizing the relevance of research in the field of studying digital platforms and the digital transformation of economic sectors, as well as the presence of mutual scientific interest in the examined issues.

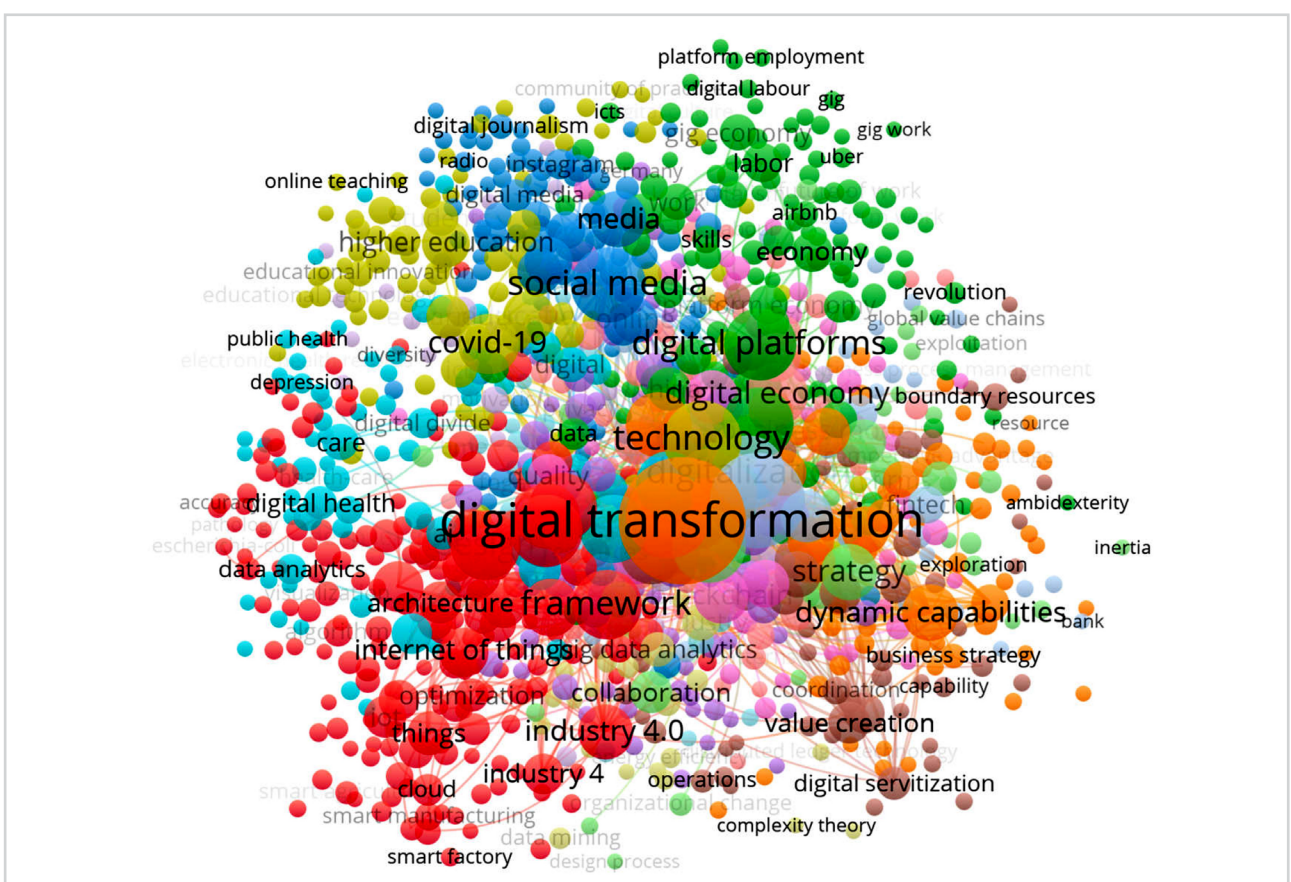

Figure 7:
Results of scientometric analysis for the query «digital platforms» and «digital transformation»
Source: Compiled by the authors

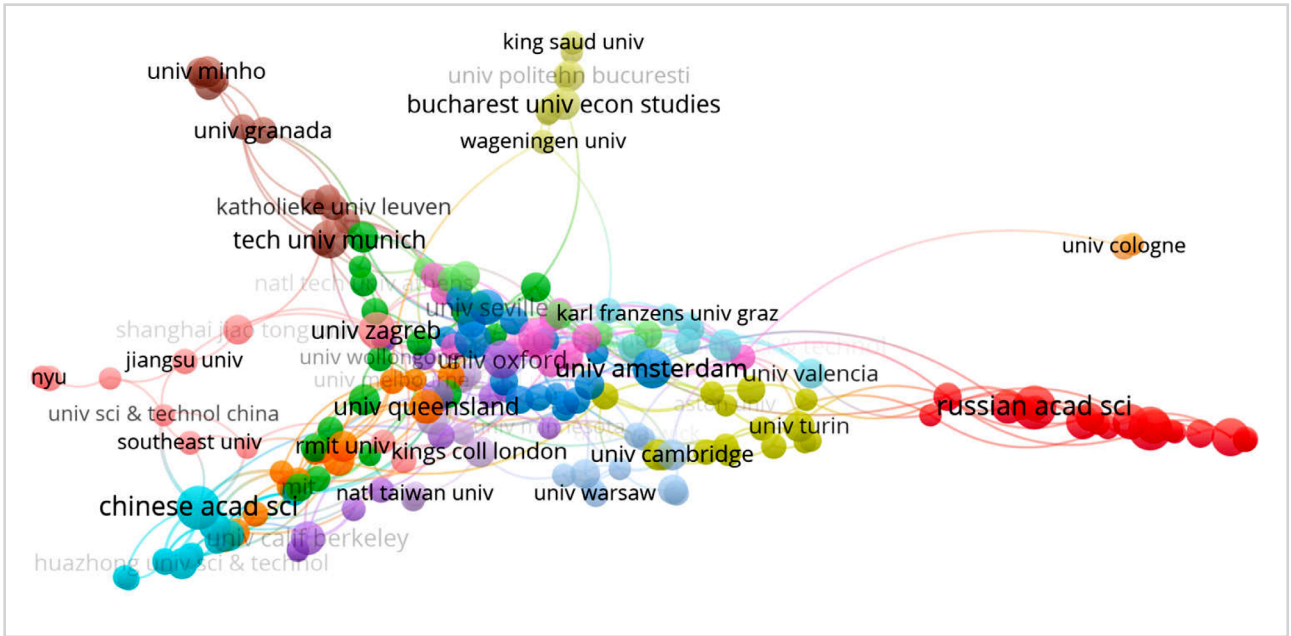

Figure 8:
Network of organizations collaboration based on co-authorship
Source: Compiled by the authors

4.1.3. General characteristics of search results ««digital transformation» and «industry 4.0»» in the Web of Knowledge database (Clarivate Analytics) and results of scientometric analysis in VOSviewer.

According to the search formula «digital transformation» and «industry 4.0» in WoS (Clarivate Analytics), a dataset consisting of 689 publications was obtained, distributed among the top 5 countries as follows: England - 69 articles (10.02%), Italy - 68 (9.87%), China - 63 (9.15%), Germany - 62 (9%), and Spain - 57 (8.27%).

It's important to note regarding scientific publications that they are presented in the form of articles published in such scientific journals as «Sustainability» - 89 articles (12.9%), «Applied Sciences Basel» - 29 (4.2%), «IEEE Access» - 24 (3.5%), «Technological Forecasting and Social Change» - 14 (2%), «Journal of Innovation Knowledge» - 12 (1.7%), «Digital Transformation» - 11 articles (1.6%), that also serve as significant collaborative platforms for presenting and exchanging research accomplishments in the field of digital transformation within the context of Industry 4.0.

The results of the analysis leads to a conclusion that in the overall publication dataset, 38.76% are research papers categorized under «Management» - 116 articles (16.84%), «Business» - 106 publications (15.39%), and «Economics» - 45 works (6.53%), proving the importance of understanding and effectively managing digital transformation processes in business and economics.

According to the bibliometric data from the WoS database, the leading organizations funding research in the field of ««digital transformation» and «industry 4.0»» are the European Union, the National Natural Science Foundation of China, and Coordenacao de Aperfeicoamento de Pessoal de Nivel Superior (CAPES), that to some extent corresponds with the universities that have published the highest number of articles on the scientific topics considered in this context - Silesian University of Technology, University of Zagreb, and Centre National de la Recherche Scientifique (CNRS).

Table 2 lists researchers, whose work focuses on studying the distinctive features of digital transformation and Industry 4.0, and also touch on aspects of digitization, including the development of innovative business models, ensuring and adapting sustainable and customized production systems, and fostering the necessary skills among employees to operate in the new realities of organizational activity.

Conversely, the conducted scientometric analysis allowed to obtain 7 thematic clusters, characterizing the theoretical and practical aspects of the considered thematic query (Figure 9).

Let's provide a brief description of each of the presented clusters:

1 cluster - Implementation (blue): is associated with aspects of implementing and adapting digital tools in practical activities and production processes;

2 cluster - Smart Manufacturing (red): reflects the need for the implementation and adjustment of digital manufacturing, including the use of digital twins, cyber-physical systems, and artificial intelligence;

3 cluster - Industry 4.0 (green): this cluster allows for the identification of scientific publications in the theoretical and practical study of the advantages and disadvantages of digital

Table 2:
TOP - 5 scientists with the largest number of publication in the field of «Digital transformation» and «Industry 4.0»

Name of the scientist	Number of publications	h-Index (WoS)	University	Most cited article(s) by subject / number of citation
Müller, Julian Marius	7	19	Seeburg Castle University	Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Journal of Business Research, 132, 2-17 /530 citations.
Akyazi, Tugce	4	8	University of Deusto	Akyazi, T., Goti, A., Bayón, F., Kohlgrüeber, M., & Schröeder, A. (2023). Identifying the skills requirements related to industrial symbiosis and energy efficiency for the European process industry. Environmental Sciences Europe, 35, 54 / 51 citations.
Caiado, Rodrigo	4	20	Pontifícia Universidade Católica do Rio de Janeiro	Caiado, R. G. G., Scavarda, L. F., Azevedo, B. D., de Mattos Nascimento, D. L., & Quelhas, O. L. G. (2022). Challenges and Benefits of Sustainable Industry 4.0 for Operations and Supply Chain Management - A Framework Headed toward the 2030 Agenda. Sustainability, 14, 830 (2022) / 34 citations.
Ghobakhloo, Morteza	4	25	Kaunas University of Technology	Fathi, M., & Ghobakhloo, M. (2020). Enabling Mass Customization and Manufacturing Sustainability in Industry 4.0 Context: A Novel Heuristic Algorithm for in-Plant Material Supply Optimization. Sustainability, 12(16) / 23 citations.
Goti, Aitor	4	8	University of Deusto	Akyazi, T., Goti, A., Oyarbide, A., Alberdi, E., & Bayon, F. A. (2020). Guide for the Food Industry to Meet the Future Skills Requirements Emerging with Industry 4.0. Foods, 9(4), / 46 citations.

Source: Compiled by the authors based on the search query «digital transformation» and «industry 4.0» in the Web of Science (Clarivate Analytics)

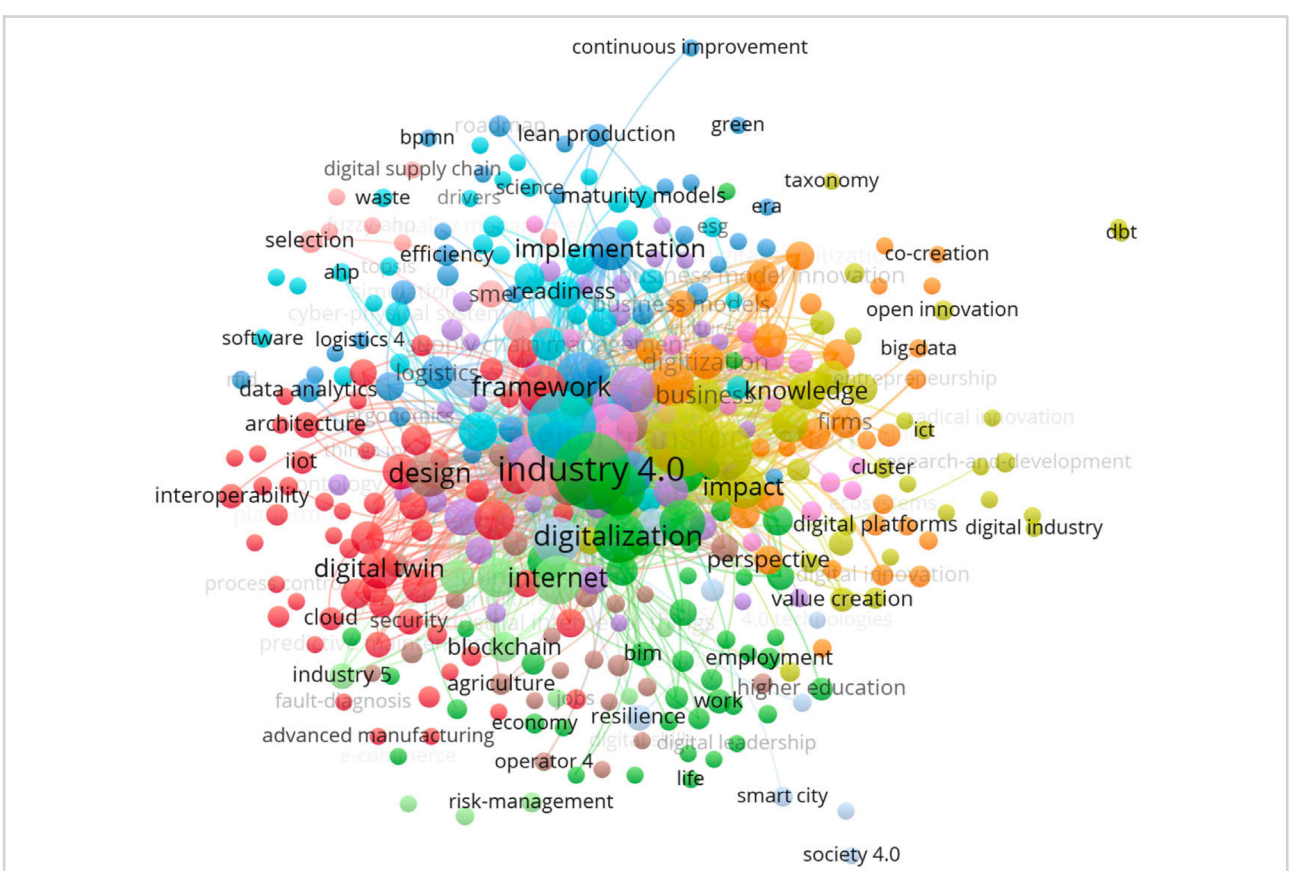

Figure 9:
Scientometric analysis of publications in the context of the search query «digital transformation» and «industry 4.0»
Source: Compiled by the authors

transformation in industrial production during the Fourth Industrial Revolution, as well as evaluating the digital potential of enterprises, industries, countries, and regions worldwide.

4 cluster - Digital Transformation (mustard): directly reflects the directions and possibilities of digital transformations in various sectors of the economy;

5 cluster - Internet (light-green): is identified with research dedicated to the prospective directions of the World Wide Web's development and its application in the context of digital transformations;

6 cluster - Big Data (pink): consolidates works related to exploring the possibilities of using big data, including within the operations of industrial enterprises;

7 cluster - Transformation (orange) and ***8 cluster - Readiness*** (light blue): are dedicated to research reflecting the assessment of companies' readiness for digital transformations, the potential for implementing new quality management standards, and the study of barriers hindering digital restructuring.

4.2. Implementation features of digital ecosystems by industrial enterprises: the experience of Kazakhstan and Russia.

The digital ecosystem encompasses the entire spectrum of the industrial landscape, including production, supply chains, logistics, and customer interactions, implies the active development of innovative technologies and products, emphasizes the interconnectedness of digital tools and their collective contribution to the overall sustainability and competitiveness of industrial enterprises in the era of digital transformation.

Research by the international consulting company McKinsey has confirmed that the application of an ecosystem approach allows companies to generate more revenue, engage in economically beneficial partnerships, and reduce operational expenses. From a strategic perspective, such partnerships also provide companies with access to innovations driven by digital technologies and ongoing industry transformation.

In modern realities industrial enterprises in Kazakhstan and abroad are transforming into digital companies, characterized by the automation of numerous traditional business processes, as well as changes regarding the way these companies interact with competitors, suppliers, and consumers within the framework of a digital ecosystem. Table 3 illustrates the use of digital ecosystems by manufacturing companies in the Republic of Kazakhstan and the Russian Federation.

It should be mentioned that today, it is crucial for industrial enterprises to not only deploy digital ecosystems but to switch to their customized versions, since it allows emphasizing individuality and shaping the strategic orientation of industrial enterprises, providing them with competitive advantages in the rapidly changing digital world.

Thus, among the distinctive features of a customized digital ecosystem are:

- ***personalization and adaptation:*** elements of the ecosystem are carefully designed and tailored to fit the specific characteristics of the enterprise; adapting functionality, user interfaces, and integration with existing systems is carried out;
- ***integration of specific solutions and technologies,*** inherent to a particular industry, ensuring maximum functionality and efficiency;
- ***security and control:*** accounting for specific security requirements contributes to creating a high level of data protection and access control, that is particularly crucial for industrial enterprises and complex integrated industrial structures, such as those represented by industrial clusters;
- ***system responsiveness:*** enables the quick implementation of new functions, process optimization, and adaptation to changes in the business environment;
- ***efficient resource utilization:*** customized solutions contribute to the effective allocation of budget and resources;
- ***unique business strategy:*** facilitates obtaining maximum benefits from the use of digital technologies.

On the international market, there are numerous companies employing customization techniques. For example, the successful French company Leroy Merlin allows customers to design kitchen sets with the assistance of free designers. Defense industry enterprises also implement partial customization solutions. Thus, the joint Italian-Russian venture «SuperJet International» enables the customization of the Superjet-100 cabin and aircraft final adjustments to meet the specific requirements of individual customers at the Sukhoi civil aircraft (SCA) Supply Center in Zhukovsky for Russian clients and in Italy at the SuperJet International facility for international customers (Akzhigitova, 2019).

Table 3a (Kazakhstan):
Examples of implementation and adaptation of digital ecosystems / digital platforms on the basis of industrial enterprises in Kazakhstan and Russia

Company name	Implemented digital ecosystems / digital platforms	KPI of ecosystem / platform
The Republic of Kazakhstan		
JSC «Qarmet»	SAP ERP Business Process Management System; electronic delivery invoice for the goods (DIG); Dow Jones online platform; Project «Designed system for emergency alerting, personnel and mobile equipment positioning with mobile radio communication function».	SAP ERP enables the consolidation of all company departments into a unified information space, efficient data processing and decision-making; reduces the number of IT systems and applications by unifying processes and data formats. The Electronic delivery invoice for the goods (DIG) is integrated with the portal of the Committee of State Revenues, simplifying the process of necessary document completing. To verify the reliability of counterparts, an online platform Dow Jones has been implemented, minimizing sanction and corruption risks. It is important to note that the pilot project implemented at the «Kazakhstanskaya» mine to enhance industrial safety and fully automatization of mining equipment, known as the «Designed system for emergency alerting, personnel and mobile equipment positioning with mobile radio communication function», with a cost of 1.5 million US dollars, involves video monitoring of mining operations, automatic gas concentration alerts, and self-diagnosis of equipment.
LLC «Kazakhmys Holding»	Unified management platform for integrating information systems that ensure business processes management at LLP «Kazakhmys Holding», including: electronic document management module within the enterprise and with external partners (counterparties and clients); business process management module; meetings management module; knowledge base, digital workplace - dashboard. Monitoring system for the condition of technological equipment with the RAPID SCADA software complex. «Mine Production Management System» and DMMS (Digital Monitoring & Management System).	The unified holding management platform ensures the efficient integration of all information systems necessary for coordinating all business processes at LLP «Kazakhmys Holding». The monitoring system for the condition of technological equipment with the RAPID SCADA software complex – an industrial automation platform that provides a single point of access to technological information about the state of the production process; collection and store technological parameters of the AMS TP in a unified information space of the enterprise. «Mining Production Management System» (deployed for Mine No. 67 of the «Zapadny» minery), also the digital solution DMMS (Digital Monitoring & Management System) and its modules allow real-time determination of the locations of objects on an interactive map, indicating the equipment's operational status and key performance indicators of personnel and mobile machinery, notifies staff of emergency situations, monitors data for all indicators, conducts video surveillance, automatically and continuously measuring air quality, analyzes and controls equipment conditions, as well as has ability to issue tasks for personnel and machinery.
JSC «National nuclear company «Kazatomprom»	Digital platform «eKAP» for the automation and integration of business processes across all enterprises of Kazatomprom; digital twin of the geotechnological field of the mining complex «Mining-Geological Information System», at the enterprise of LLC «RU-6»; corporate SAP-ERP enterprise resource planning system; «Digital Workforce» ecosystem, which includes an e-learning system, online monitoring of personnel health (wearables), and virtual desktop workplace (Desktop-as-a-Service).	The use of digital products, such as the «eKAP» platform, ensures effective integration and management of processes across all enterprises, enhancing the efficiency and transparency of interactions. The digital twin optimizes mining processes, improving forecasting and resource management through the information system. The corporate SAP-ERP system and the «Digital Workforce» ecosystem with e-learning, online health monitoring, and virtual workplaces enhance business efficiency and employee well-being by optimizing processes and increasing resource accessibility.
JSC «AK Altynalmas»	Digital mine for managing a gold extraction plant, including the SAP ERP system, 3DEXPERIENCE, Manufacturing Execution System (MES), IoT, IntelliSense intelligent solution technology, electronic signature-based personnel work-order management system, and the Mine Advisor platform with a database of mining-geological developments. An IT- infrastructure - a digital landscape has also been created: optical communication channels (in the deposits of Aktogay and Akbakay); underground Wi-Fi at the «Beskempir» and «Akbakai» mines for transmitting information to the surface through tablets and mobile devices; a dispatch center at Aktogay operating online with information systems for monitoring the entire production chain, vehicle movement, and efficient management of mining processes.	Automating business processes based on the SAP S/4HANA solution and model companies allows for optimizing operational costs by 15%, working capital by 5%, and reducing the number of routine operations by 20-30%. The implemented project «Digital Twin for Sag Mill» optimizes the operations of Mill No. 1, as well as, using a cloud-based big data analysis system based on artificial intelligence allows forecasting potential overloads within a twenty-minute interval for timely response, prevention, or mitigation of overloads. Virtual sensors for ball load and liner condition on the mill predict wear on drum liners, eliminating technological downtime associated with measuring the ball level on the mill, where an average of 100 minutes per month was previously lost.

Source: Compiled by the authors based on the companies' websites

American manufacturing companies like Tesla and Nike also offer users customized products tailored to their preferences, utilizing the concept of the «new» robotic enterprise.

Undoubtedly, the implementation and utilization of digital ecosystems by industrial enterprises contribute to various positive effects, including:

- increase of organizational competitiveness level;
- possibilities of entry into new markets;
- reduction of expenses for acquiring new customers;
- strengthening of customer loyalty and increase of customer base;
- generation of revenue from additional activities;
- increase of investment attractiveness;
- brand strengthening and increase of business value;
- acceleration of innovation (development and implementation of new technologies and solutions);
- real-time data monitoring and management;
- optimization of the supply chain through improved coordination between suppliers, manufacturers, and distributors.

The disadvantages of introducing and adapting digital ecosystems in the activities of industrial enterprises include the following factors:

Table 3b (Russia):
Examples of implementation and adaptation of digital ecosystems / digital platforms on the basis of industrial enterprises in Kazakhstan and Russia

Company name	Implemented digital ecosystems / digital platforms	KPI of ecosystem / platform
The Russian Federation		
PJSC «Magnitogorsk metallurgical plant» (MMK)	MMK's digital platform includes basic software products in seven key areas of development and operation of MMK's information systems: application of digital twins; development of cloud servers; data development and analytics; IoT development; increased technological mobility; digitization of employee interactions; application of robots and unmanned tools.	The unified digital platform allows optimizing the timing and cost of implementing digital projects, ensuring a multiple increase in the scale of digitization. Key performance indicators for the business units' performance, taking into account the use of digital solutions, include up to a 25% reduction in the cost of implementing digital projects, up to a 20% reduction in support costs, and up to a 60% acceleration in project implementation.
LLC «Gazprom neft NTC»	A digital ecosystem in the field of exploration and production, deep oil processing, encompassing all aspects of activities from geology to the knowledge-sharing process among the company's divisions.	The IT-project program ERA coordinates technological processes within this oil company. The key performance indicators (KPIs) of the program are expressed in increased oil production, improved oil recovery coefficient, and reduced capital and operational costs.
The «Sofia» group of companies	A unified digital ecosystem with an integrated tender sales process on «1C: ERP Enterprise Management» aims to facilitate collaboration among a group of companies within a unified digital ecosystem; optimizing the cost of owning IT solutions: transferring information from «1C: UPP» to «1C: ERP»; automating the end-to-end process of tender sales and procurement.	The economic impact of implementing the digital ecosystem is reflected in a 20% reduction in labor costs, a 100% acceleration in obtaining management reports, a 15% reduction in expenses for material and administrative resources, a 15% reduction in service delivery times, and a 15% increase in profit.
JSC «Izhorsk Pipe Plant» (subsidiaries of OJSC «Severstal»)	The «Cometal» platform brings together the manufacturing capabilities of over 170 metal processing and machine building partner enterprises, which handle various orders.	The launch of the «Industrial. Market» marketplace, targeting the B2B sector, where industrial and construction companies have direct access to orders/purchases from major industrial consumers of their products through a unified platform.
PJSC «KAMAZ»	Intelligent transport – information system ITIS – KAMAZ on the trucks of K5 generation. Additionally, PJSC «KAMAZ» sets the task of creating new digital services incorporating insurance and leasing services, a digital platform where the vehicle is an integral part of the Internet of Things.	The implemented Intelligent Transport and Information System improves the vehicle's operational parameters, such as fuel consumption and wear on components, reduces logistics costs. Adapted digital services also enable efficient solutions to customer tasks, including the launch of a virtual sales office truckinstock.com, management of logistics requests on the platform cargorun.ru, and online rental of specialized equipment on specsharing.ru. There is a transition to the «Vehicle as a Service» business model through the integration of business processes of service and dealer centers.

Source: Compiled by the authors based on the companies' websites

- significant initial costs (including equipment, software, and staff training);
- cybersecurity risks requiring effective protection against industrial espionage;
- functional compatibility issues: integrating different technologies and systems into the ecosystem may lead to compatibility problems.

Summarizing all above, it is important to note that the implementation of digital ecosystems provides participants in the industrial sector with a wide range of benefits, contributing to overall development and market success, but also, it requires thoughtful strategic planning, maintaining a balance between benefits and costs, as well as careful consideration of potential issues, along with effective risk management.

5. Discussions

The study of international scientific works revealed a number of issues that must be reconsidered in light of market changes and the digital transformation of industrial enterprises. One important research area is the disruptive impact of digital ecosystems on employment structure and labor dynamics. This includes crucial aspects such as the possibility of automation and creation of new job positions. Unresolved questions remain regarding how digital transformation will affect overall employment and how the workforce should be prepared for upcoming changes.

Additional research gaps have been found in the area of long-term environmental and economic sustainability of digital ecosystems. This involves the need to assess the environmental impact of growing digitization. A subject of debate revolves around finding a balance between the benefits of digital transformation and its potential environmental costs, as well as pursuing sustainable practices. These research questions underscore the necessity for more thorough and interdisciplinary studies, that consider the broad implications of digital transformation for society, the environment, and various business functions.

The authors' future research will focus on development a methodology for assessing the digitization level of industrial enterprises based on a holistic approach and its validation using examples from industrial companies in Kazakhstan.

6. Conclusion

Modern companies realize that in a rapidly changing economic environment, it is challenging to achieve leadership positions on their own. The formation of digital ecosystems becomes a key

part of growth and survival strategies. The drive for business organizations to provide broader access to their products and services, along with the need to eliminate geographic barriers, contributes to the formation of global digital ecosystems.

The conducted research has demonstrated that the issues of exploration the aspects of formation of digital ecosystems in industrial enterprises within the context of their digital transformation is relevant for the scientific community and holds significant practical value for company executives, governmental and research organizations involved in funding such studies.

As a result of the authors' research, based on a theoretical-practical approach, an original concept of the digital ecosystem of an industrial enterprise was proposed, its distinctive features and advantages were identified, a conceptual structure was presented, and examples of the practical implementation of digital ecosystems in the activities of industrial enterprises in the Russian Federation and the Republic of Kazakhstan were considered.

Carried out scientometric analysis of publications has provided an overview of current and prospective scientific directions in the field of digital ecosystems and digital transformation in the context of Industry 4.0., identified leading countries, prominent scientists, and research organizations within the scope of the discussed issues.

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