

INDUSTRY 4.0 APPLICATIONS BASED ON THE BUSINESS MODEL CANVAS

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Purpose: The aim of the article is to indicate in which areas of the Business Model Canvas (BMC) companies use Industry 4.0 technologies and which Industry 4.0 technologies are most frequently used in BMC.

Design/methodology/approach: The study uses a mixed-methods approach, combining a systematic literature review with a quantitative survey to analyze the application of Industry 4.0 technologies across the nine areas of the Business Model Canvas. A matrix framework integrating selected technologies with BMC elements enables both literature analysis and empirical validation based on survey data from enterprises.

Findings: The research revealed that the technologies most widely used in BMC include Big Data & Artificial Intelligence, Cloud Computing, Internet of Things, and Industry Internet of Things. In turn, the areas with the greatest application of Industry 4.0 technologies at BMC are: value proposition, key activities, and key resources.

Research limitations/implications: In the case of survey research, the limitation is the sample size from specific geographic areas. Other significant limitations include the level of awareness of digital transformation in organizations, which will change over time.

Practical implications: From a research perspective, the study's findings will enable other researchers to continue their research to better understand the applications of Industry 4.0 technologies in selected BMC areas or industry sectors. In turn, entrepreneurs will be able to implement specific Industry 4.0 technologies in selected BMC areas.

Social implications: Entrepreneurs may prioritize implementing Industry 4.0 technologies such as Big Data & Artificial Intelligence, Cloud Computing, Internet of Things, and Industry Internet of Things. They can also begin implementing these technologies in areas of the business model such as the value proposition, core activities, and key resources.

Originality/value: Unlike other previous studies, this provides insight into the application of Industry 4.0 technologies in each of the nine BMC areas.

Keywords: Business Model Canvas, Industry 4.0, survey research.

Category of the paper: Research paper.

1. Introduction

Industry 4.0 is a paradigm that encompasses the convergence of digital and physical technologies, which is expected to bring greater efficiency to manufacturing and service companies. The term and concept known as “Industry 4.0” was proposed in 2011 by a German federal government initiative involving universities and private companies, and was later popularized during the Hannover Messe trade fair in 2011 (Kagermann, Lukas, Wahlster, 2011) (Ortt, Stolwijk, Punter, 2020). But what is "Industry 4.0"? Currently, there are many similar definitions. For the purposes of this article, the following definition was adopted: "Industry 4.0 is an idea, vision, concept based on a paradigm in which the process of integrating resources at the digital and physical level takes place in order to create intelligent organizations characterized by a high degree of production efficiency". Specific technologies attributed to Industry 4.0 are important in this process, such as: data integration systems, autonomous robots and cobots, drones, AGV technologies, digital Twins, cyber-physical systems, the Internet of Things, sensors, cybersecurity, cloud computing and analysis using artificial intelligence and machine learning algorithms, 3D printing, communication technologies such as RFID or 5G, augmented and virtual reality (Jamwal, Agrawal, Sharma, Giallanza, 2021). The complexity of the processes related to the transformation towards Industry 4.0 forces companies to adopt appropriate implementation strategies, tailored to the type of business or project characteristics (Müller, Buliga, Voigt, 2018; Śledziowska, 2025). Questions arise: which technologies should be implemented to achieve the intended effects? In which areas of the business model should they be applied? The business model, in particular, is a crucial issue. Research has shown that companies struggle to generate profits from new technologies without implementing appropriate business models (Abdelkafi et al., 2013). Considering the level of saturation with modern technologies, technologies within the Industry 4.0 concept, this problem will intensify among many enterprises taking up the challenge based on digital transformation towards Industry 4.0.

2. Framework & research questions

Transformation towards Industry 4.0 in an enterprise can proceed discreetly (stepwise), taking into account the enterprise's current technological infrastructure in the process of collecting, analyzing, and using data (e.g., through sensorization, introducing selected Industry 4.0 technologies into production), but also in a way that allows the enterprise to radically modernize towards Industry 4.0. The degree of technological change will largely depend on the enterprise's investment capabilities and the goals it intends to achieve through the

implementation of new technologies. The issue of applying Industry 4.0 technologies in an enterprise arises. This raises questions: in which areas of operations should the enterprise apply Industry 4.0 technologies? Which of these technologies should be applied in a given area of the enterprise? To answer these questions, a simple yet universal framework is needed.

This framework reflects the business activities of enterprises across various industries and sectors, while also allowing for the placement of Industry 4.0 technologies within it. This requirement is met by the Business Model Canvas template, which consists of nine blocks. Five blocks: customer segment, value proposition, channels, customer relationships, and revenue streams represent the area directly related to the customer, while the blocks: key resources, key activities, key partners, and cost structure represent the back-end of business model implementation. All these blocks allow for the creation of not only a business model but also the analysis of various business models and strategies for the organization's needs. Each of these blocks can be analyzed as an area of potential application of Industry 4.0 technologies. This structure allows for easy identification of specific applications of Industry 4.0 technologies in a given element of the business model, e.g., the use of AI with robots to manage production processes or the use of Digital Twin technology to develop functionalities and features for new product value propositions. This creates the basis for the need for research, the results of which will provide answers to research questions such as:

RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC?

RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies?

RQ3: Which Industry 4.0 technologies are most frequently used in BMC?

This leads to a specific research goal: identifying the areas of BMC in which companies use Industry 4.0 technologies. Obtaining answers to these questions will help determine future directions for implementing Industry 4.0 technologies in specific areas of the business model.

3. Research design

3.1. Research area

The research area focuses on the application of Industry 4.0 tools within specific areas of the Business Model Canvas (BMC) template (Osterwalder, Pigneur, 2010). The framework for the research area was therefore individual BMC areas, such as: customer segment, value proposition, channels, customer relationships, revenue sources, key resources, key activities, key partnerships, and cost structure. Each of the aforementioned blocks (elements) represented a specific area for the possible application of selected Industry 4.0 tools by enterprises.

The choice of the BMC template as the basic framework within the research area is justified by the tool's widespread recognition among many organizations, including most enterprises of all sizes. The selected set of Industry 4.0 technologies served as a basic selection list for the application of a specific technology in each of the nine elements of the template. This allowed for data collection and subsequent analysis for each of the nine BMC areas, as well as for a cross-sectional analysis of selected technologies across all BMC areas. Combining BMC with Industry 4.0 technologies allowed for the creation of a matrix within which the study could be conducted. Therefore, BMC templates and selected Industry 4.0 technologies constituted the foundation for the SLR-based study (Snyder, 2019) and the quantitative study based on a survey addressed to enterprises.

3.2. Research methods

Two research methods were used for this study. The first research method was a systematic literature review. The second research method was a quantitative survey-based study. (Creswell, Creswell, 2022; Fisher, 2017). A detailed description of the selected research methods is provided below.

The systematic literature review method aimed to first identify Industry 4.0 technologies used in specific research areas within the BMC template. The systematic literature review was conducted by developing keyword combinations, which were then used to conduct a search for articles through search engines in databases of scientific articles presenting applications of Industry 4.0 technologies in specific areas of the BMC template. Based on this, a database of articles was created. These articles were then further identified for their applications in BMC areas, enabling further selection based on the research objective and research questions. The research process was then continued using the developed matrix. This matrix consisted of the following fields: ordinal number, article authors, article title, year of publication, country of the lead author, publisher, number of citations, abstract, research methods, research hypotheses, research questions, research area, research objective, and nine BMC areas: value proposition, customer segments, customer relations, channels, key activities, key resources, key partners, sources of revenue, and cost structure. Each of these nine areas contained 15 Industry 4.0 technologies: AI - Artificial Intelligence Algorithms, CC - Cloud Computing, IoT - Internet of Things, IoTT - Industry Internet of Things, CS - Cybersecurity, CP - Cyber-physical, DT - Digital Twin, AM - Additive Manufacturing: 3D Printing, AR - Augmented Reality, BC - Block Chain, XG - 5G,6G, QC - Quantum Computing, EC - Edge Computing, MES - Manufacturing Execution System; RA - Robotics and Automation.

Table 1.

Analysis of Industry 4.0 technologies in selected articles: - no technology X-technology was mentioned in the article

Technologia	(Kagermann, Lukas; Wahlster, (2011))	(Sigov, Ratkin, Ivanov, Xu, Li. (2022))	(Tsaramiris et al. (2022)); (Oks et al. (2022)),	(Oks et al. (2022))	(Jamwal et al. (2021))	(Logeswaran et al. (2024))	Rath, Khang (2024))	(Alqoud et al. (2022))	(Mithas et al. (2022))	(Ghobakhloo et al. (2022)).
AI	-	X	X	-	X	X	X	X	X	X
CC	-	X	X	X	X	X	X	X	X	X
IoT	X	X	X	X	X	X	X	X	X	X
IIoT	✓	X	X	X	X	X	X	X	X	X
Cs	-	X	X	X	X	X	X	X	X	X
Cp (CPS)	✓	X	X	X	X	X	X	X	X	X
DT	-	X	X	X	X	X	X	X	X	X
AM	-	X	X	-	X	X	-	X	X	X
AR	-	X	X	-	X	X	-	X	X	X
BC	-	X	X	-	X	X	-	X	X	X
XG (5G/6G)	-	X	X	-	X	X	X	X	X	X
QC	-	X	-	-	-	X	-	-	X	-
EC	-	X	X	X	X	X	X	X	X	X
MES	-	-	X	X	X	X	-	X	X	X
RA	-	X	X	X	X	X	-	X	X	X

Source: Authors own work.

The selection of Industry 4.0 technologies for the list is justified by scientific sources such as: Kagermann, Lukas, Wahlster, 2011; Sigov, Ratkin, Ivanov, Xu, 2022; Tsaramiris et al., 2022; Oks et al., 2022; Jamwal et al., 2021; Logeswaran et al., 2024; Rath, Khang, 2024; Alqoud et al., 2022; Mithas, et al., 2022; Ghobakhloo et al., 2022). They constituted a canon for research purposes regarding the applied Industry 4.0 technologies. These articles list and describe Industry 4.0 technologies. The table 1 shows which of the articles indicates a given technology. Together, the above-mentioned articles allowed the creation of a complete, fully consistent, and ordered list of Industry 4.0 technologies. However, it is worth emphasizing that over time, new technologies of significant importance may appear and will be included in the Industry 4.0 set, therefore the developed list is functional in nature. It is not a normative list. This list is not intended to be theoretically exhaustive of the entire Industry 4.0 ecosystem. The list we constructed contributes to the analytical matrix as part of our systematic literature review. We treat the developed list as an operational reference set that forms the analytical matrix. Based on this matrix, information was gathered on the applications of specific Industry 4.0 technologies in each area of the BMC template. The collected data were used to develop statistics on the application of specific Industry 4.0 technologies in each area of the BMC template. The collected results enabled the identification of research methods, hypotheses, and research questions, thus identifying research gaps, as well as opportunities for developing new directions for future research, new research questions, and hypotheses. The results also had a practical impact, indicating which Industry 4.0 technologies may be key in their application in specific areas of the business model. The figure 1 below illustrates the subsequent stages of the method based on a systematic literature review.

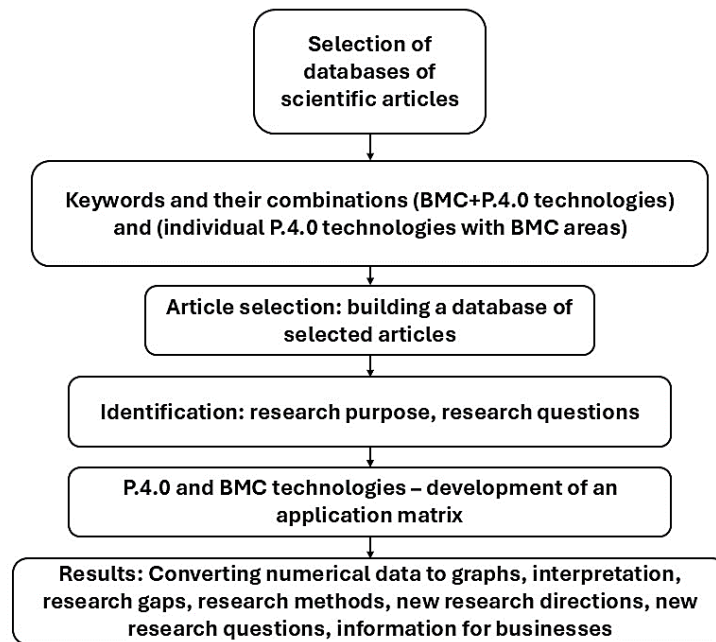


Figure 1. Schematic diagram of the systematic literature review conducted.

Source: Authors own work.

During the literature analysis, we used the following exclusion criteria:

1. The publication was outside the timeframe of the 2021-2025 study.
2. The document is not classified as an article or book chapter.
3. No explicit reference to Industry 4.0.
4. No explicit reference to one of the Industry 4.0 technologies.
5. Publications not directly related to the application of Industry 4.0 technologies in business, e.g., focusing on applications in government administration.

During the literature analysis, we used the following inclusion criteria:

1. Peer-reviewed scientific or industry publication.
2. The publication must explicitly use the term Industry 4.0 or explicitly refer to the Industry 4.0 architecture (RAMI 4.0).
3. The publication must mention at least one Industry 4.0 technology.
4. The publication must mention business applications that relate to BMC areas.
5. The publication must indicate the research methods used. As part of the research methods, a quantitative research approach was applied, based on a specially developed questionnaire. This research method was chosen due to its ability to empirically examine the use of 'Industry 4.0' technologies by enterprises within the individual areas of the BMC template. The quantitative, survey-based method enables the collection of data that reflects reality. The collected data makes it possible to obtain concrete, factual cognitive results not only through quantitative analysis and visualization in the form of charts, but also through the use of descriptive statistics. The questionnaire included multiple-choice questions (allowing the selection of several options). The multiple-

choice format makes it easy to construct questions regarding the application of Industry 4.0 technologies in each of the nine areas of the BMC template.

The following questions were developed:

1. Does your organization use Industry 4.0 technologies for customer segmentation? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
2. Does your organization use Industry 4.0 technologies to create value proposition for customers? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
3. Does your organization use Industry 4.0 technologies to optimize distribution channels? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
4. Does your organization use Industry 4.0 technologies to build relationship with customers? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
5. Does your organization use Industry 4.0 technologies to manage key activities? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
6. Does your organization use Industry 4.0 technologies to collaborate with key partners? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
7. Does your organization use Industry 4.0 technologies to optimize the revenue structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
8. Does your organization use Industry 4.0 technologies to optimize the revenue structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".
9. Does your organization use Industry 4.0 technologies to optimize the cost structure? Please, indicate the technologies that are used in your organization (you can indicate more than one). If not, check the box "are not used".

The figure 2 illustrating the steps involved in conducting a quantitative study.

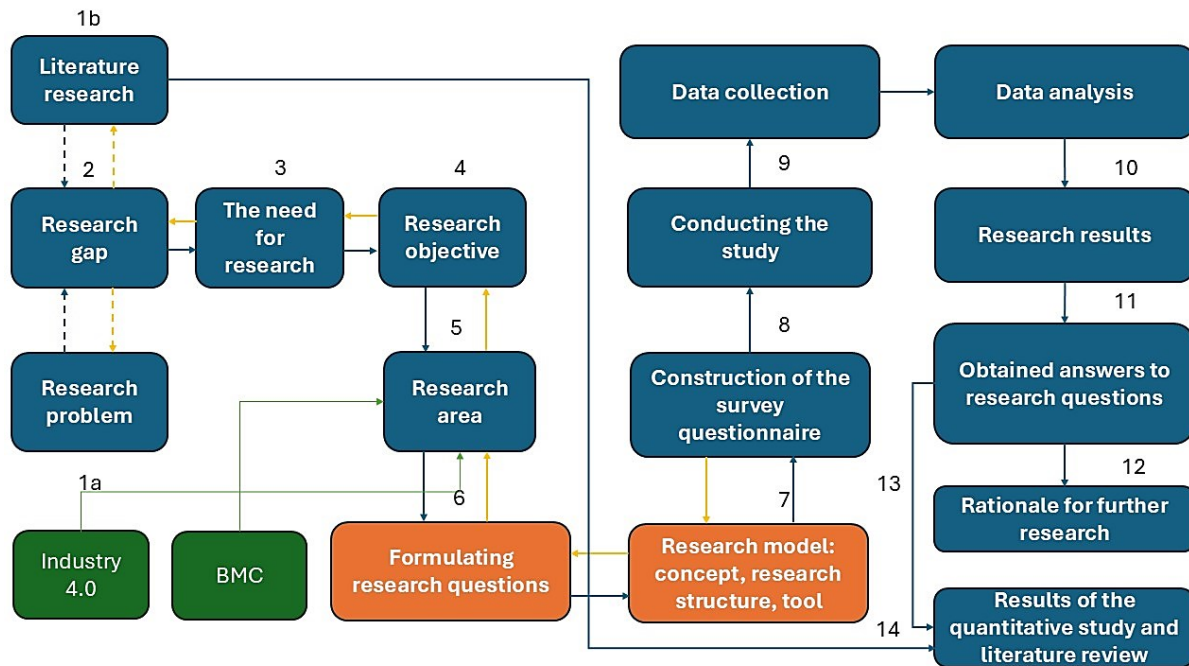


Figure 2. Diagram showing the steps involved in conducting a quantitative study.

Source: Authors own work.

The research sample was acquired during the international DEICy 2024 Digital Economy, Internet of Things, Cybersecurity (DEICy, 2024) event, which took place from November 25-29, 2024. A total of 405 entities, including enterprises, research institutes, universities, associations, and foundations, participated in the registration process. After data verification and cleaning, 359 valid records were qualified for further analysis, while 46 entries were rejected because they did not represent enterprises.

The structure of the study sample in terms of enterprise size was as follows:

- Microenterprises (1-9 employees) – 111 entities (31%),
- Small enterprises (10-49 employees) – 113 entities (32%),
- Medium-sized enterprises (50-249 employees) – 65 entities (18%),
- Large enterprises (250 or more employees) – 70 entities (19%).

In total, small and medium-sized enterprises (SMEs) constituted 81% of the study sample, while large enterprises constituted 19%.

The final research sample included only enterprises, in line with the research objectives and questions. They included:

- 211 commercial companies,
- 49 start-ups,

which together accounted for 72.5% of all registered event participants.

European companies accounted for the largest share, approximately 74%. Of these, 65% were from the EU and 9% were from Europe but outside the EU. Companies from the Middle East accounted for approximately 20%, followed by approximately 5% from East Asia.

4. Results

4.1. Literature research results

In accordance with the adopted research structure, a systematic literature review was first conducted. Based on the research objectives and research questions, 150 publications were identified and subjected to in-depth analysis using keyword combinations. The developed matrix allowed for the study, which yielded results regarding the applications of Industry 4.0 technologies within specific areas of the Business Model Canvas. Significant information regarding the application of research methods was also obtained, which allowed for the identification of gaps and new directions in research regarding the application of Industry 4.0 technologies in BMC. A detailed list of sources is presented in the References section [2-32][34-35][37-46][48-70][72-95][98-105][108-113][115-140][142-145][147-167].

First, an analysis of the research methods used was conducted. The chart below presents the percentage of individual research methods used in the area of Industry 4.0 applications.

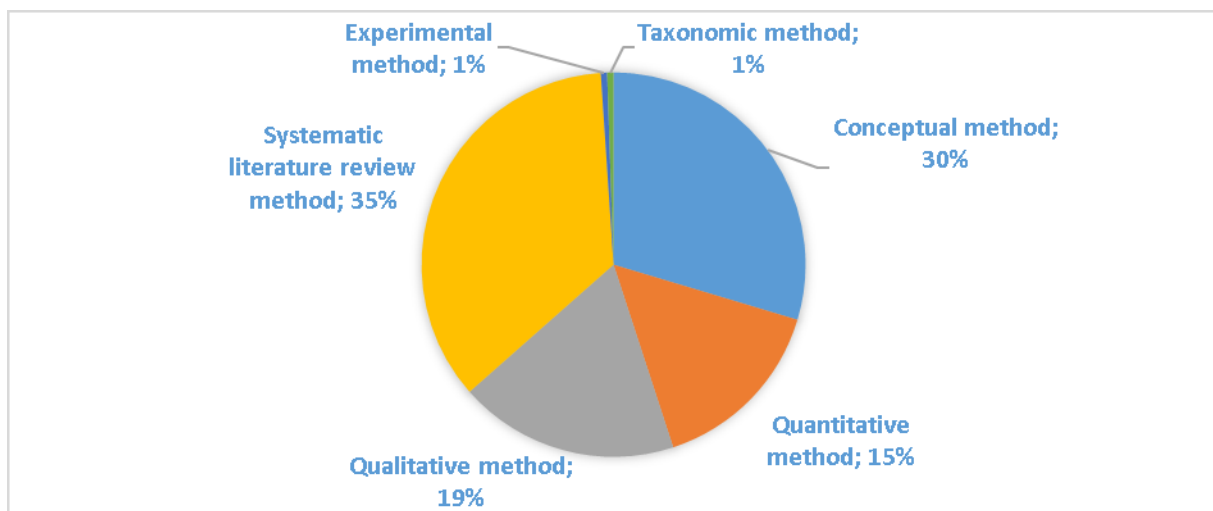


Figure 3. Percentage of research methods used on the application of Industry 4.0 technologies in BMC areas.

Source: Authors own work.

The study results (figure 3) indicate that the most frequently used research method is the systematic literature review method, with a 35% share. The conceptual method was next, with a 30% share. The qualitative method accounted for 19%. The quantitative method was next, with a 15% share. The remaining methods were the experimental research method and the taxonomic research method, both accounting for 1% of the total.

The next section of the analysis examined the number of Industry 4.0 technologies used in each area of the BMC framework. The table below presents the number of Industry 4.0 technologies used in each area of the BMC framework.

Table 2.
Industry 4.0 technologies used in individual BMC areas

	VP	CS	CR	Ch	KA	KR	KP	RE	Co
AI	21	19	21	13	39	36	9	7	12
CC	18	5	9	10	33	32	8	4	5
IoT	19	12	11	12	35	37	7	8	13
IoT	2	1	0	2	2	1	2	0	2
Cs	7	1	4	2	9	11	1	2	4
Cp	9	2	4	5	27	25	5	4	9
DT	12	3	4	6	16	13	4	2	8
AM	10	1	2	4	21	17	3	3	8
AR	7	3	6	3	13	14	3	0	4
BC	8	4	5	8	10	10	4	1	2
XG	1	1	1	1	3	3	0	0	0
QC	0	0	0	0	1	2	0	0	0
EC	1	1	1	1	2	2	0	0	0
MES	0	0	0	0	1	1	0	0	0
RA	11	2	6	6	27	28	5	5	11

Source: Authors own work.

The study results (table 2) indicate that solutions based on AI algorithms are among the most prominent Industry 4.0 technologies. Their application is particularly evident in areas such as: value proposition (21), customer relationships (21), key activities (39), and key resources (36). The next technology is CC computer cloud, which has the greatest applications in areas such as: value proposition (18), key activities (33), and key resources (32). The next technology is IoT, which has the greatest applications in areas such as: value proposition (19), key activities (35), and key resources (37). Considering IIoT technologies, the following values apply: value proposition (21), key activities (37), and key resources (38). Another prominent technology is RA robotics and automation, which has the greatest applications in areas such as key activities (27) and key resources (28). Another technology is Cyber-Physical, so-called cyber-physical technologies, the greatest applications of which are in the area of key activities (27) and key resources (25). Among other technologies, it is worth paying attention to the use of Additive Manufacturing AM technologies in the area of key activities (21) and key resources (17) and Digital Twin in the area of key activities (16) and key resources (13).

Research results also indicate which technologies have the most applications.

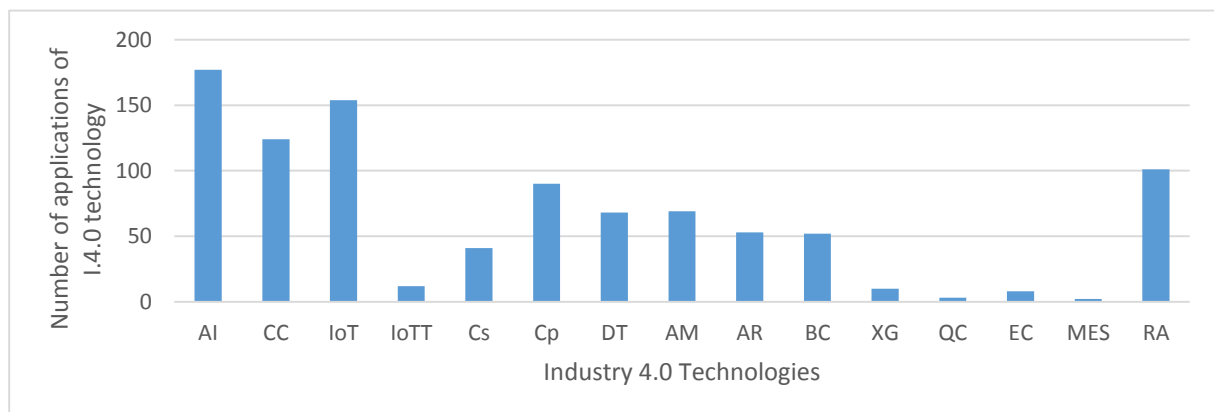


Figure 4. Application of specific Industry 4.0 technologies at BMC – SLR.

Source: Authors own work.

The figure shows that technologies such as Artificial Intelligence, Cloud Computing, IoT & IIoT stand out among Industry 4.0 technologies.

A summary analysis of the application of Industry 4.0 technologies at BMC was also conducted. The results are presented in the figure 5.

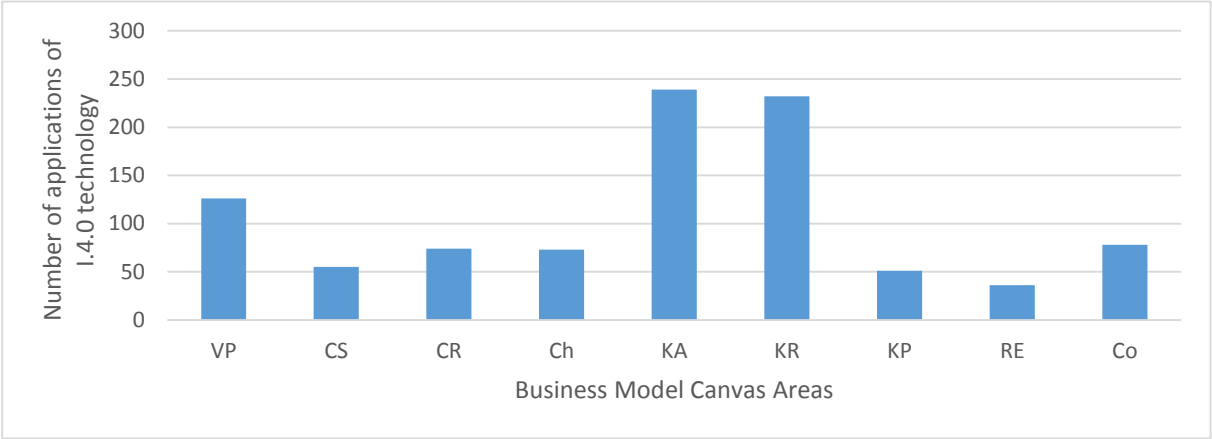


Figure 5. Application of BMC areas with Industry 4.0 technologies – SLR.

Source: Authors own work.

The study results indicate that the greatest application of Industry 4.0 technologies is in areas such as core activities (239) and key resources (232). Significant application is also noted in value propositions (126).

4.2. Survey Results

Data collected as part of the survey was first cleaned and filtered to detect irregularities, but also to ensure accuracy and consistency. Data was obtained through responses to questions during registration for brokerage meetings and the DEICy 2024 "Digital Economy, Internet of Things, Cybersecurity" (DEICy, 2024) workshops. During registration, survey participants responded to questions by indicating the application of Industry 4.0 technologies. The prepared data allowed for subsequent conversion into graphical charts and the estimation of basic statistical measures. This process resulted in two summary charts. The first chart shows the application of Industry 4.0 technologies in BMC, and the second chart shows the application of Industry 4.0 technologies in a given BMC area. These summary charts were supplemented with selected static measures, such as mean, standard deviation, and coefficient of variation. The results for the individual BMC areas are presented below.

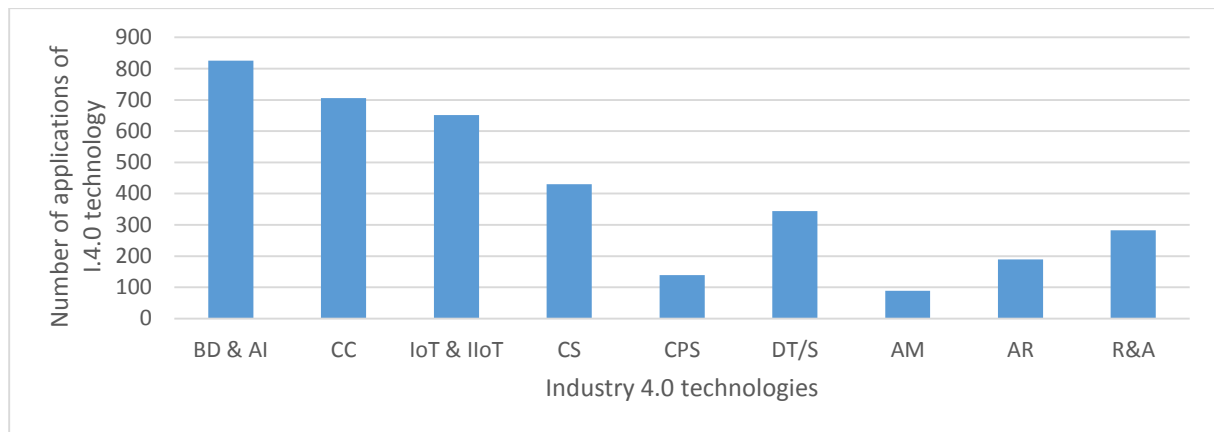


Figure 6. Applications of individual P.4.0 technologies in BMC.

Source: Authors own work.

Based on the conducted research, a figure 6 of applications of individual Industry 4.0 technologies within the BMC template concept was created. The results indicate that solutions based on BD & AI (826) are among the most prominent Industry 4.0 technologies. Cloud Computing (706) is next in terms of applications. This is closely followed by the Internet of Things (IoT) and Industrial Internet of Things (IIoT) (651). Cybersecurity (CS) (430), followed by Digital Twin/Simulation (DT/S) (344). Robotics and Automation (R&A) (283) is also prominent (189). Cyber-Physical Systems (CPS) (139) and Additive Manufacturing (AM) (89) are also prominent.

Additionally, calculations of basic statistical metrics were performed. The table below presents the values of selected metrics.

Table 3.

Selected statistical measures of the applications of individual Industry 4.0 technologies

Name of technology	Mean	Standard deviation	Coefficient of variation	Median
Big Data and Artificial Intelligence analytics	91,78	8,70	9,48%	90,00
Cloud computing	78,44	7,91	10,08%	81,00
Internet of Things or Industry Internet of Things	72,33	12,25	16,93%	71,00
Cybersecurity	47,78	6,16	12,89%	47,00
Cyber-Physical Systems (CPS)	15,44	2,30	14,87%	15,00
Digital Twin/Simulation	38,22	6,72	17,59%	39,00
Additive Manufacturing (3D Printing)	9,89	1,76	17,84%	10,00
Augumented Reality	21,00	4,64	22,08%	21,00
Robotics and Automation	31,44	7,43	23,64%	32,00

Source: Authors own work.

The table 3 shows that "Algorithms" play a greater role than "Hardware". The data in the table clearly demonstrates that digital transformation primarily occurs in the realm of algorithms and data (BD, AI, Cloud), and only then in the realm of physical machines (Robotics, 3D Printing). This approach makes it easier and cheaper to purchase access to cloud analytics than to install a robotic line. The data in the table also demonstrates the high adoption of IoT and IIoT. This demonstrates that companies are willing to invest in implementing sensors, actuators, digital meters, industrial routers, and network infrastructure, e.g., WiFi, 5G,

and combining it with existing fixed assets (even analog ones), rather than investing in new fixed assets. If companies are willing to purchase a new fixed asset, e.g., a robot, it is a "spot" purchase to improve the process at a given point in the production process. Purchasing a new robotic production line is rare. On the other hand, for IoT and IIoT, the median (71,00) is close to the mean (72,33), but the large data dispersion (deviation 12,25) and significant coefficient of variation (16,93) suggest that the market is quite polarized in this regard. This polarization is a warning sign. The gap between leaders and the rest of the companies in the IoT space will continue to widen. Companies that have not yet invested in collecting data from machines may soon lose the opportunity to implement AI. They simply will not have anything to power their algorithms. It seems that a scenario based on the "trinity" of BD&AI, Cloud Computing, IoT, and IIoT is the starting point for accelerating the transformation towards Industry 4.0 in industrial enterprises.

Another interesting comparison involved creating a chart that shows the application of all Industry 4.0 technologies in a specific area of the BMC template. This type of chart provides an overview of the saturation of a given BMC area with Industry 4.0 technologies. The results indicate that the value proposition (519) is among the areas with the highest saturation with Industry 4.0 technologies. Customer segmentation (428) is the second most important area. Next are two areas with the same results: key activities (420) and key partners (420). Key resources (402) and customer relationships (400) are next. Distribution channels (381) are next. Cost structure (350). The summary concludes with the revenue structure, with a score of (337). These results are presented in the figure 7.

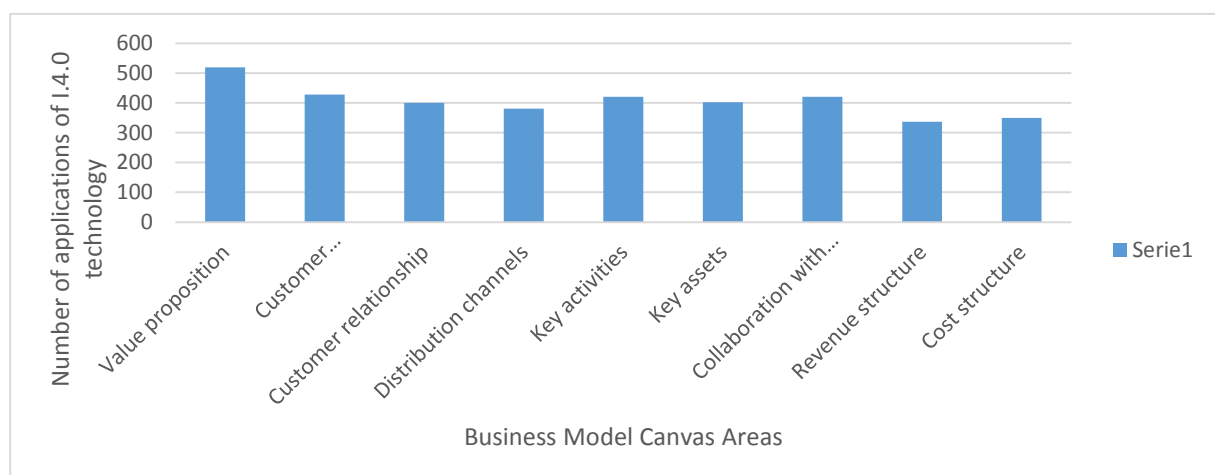


Figure 7. Application of BMC areas with Industry 4.0 technologies.

Source: Authors own work.

Figure 7 shows that value propositions, customer segmentation, and key activities are areas that can be prioritized by enterprises as part of digital transformation based on Industry 4.0 technologies. Additionally, calculations of basic statistical metrics were performed. The table 3 below presents the values of selected metrics.

Table 4.*Selected statistical metrics of Industry 4.0 technology saturation in specific BMC areas*

Name of technology	Mean	Standard deviation	Coefficient of variation	Median
Value proposition	57,67	35,34	61,29%	52
Customer segmentation	47,56	29,45	61,93%	41
Customer relationship	44,44	30,17	67,89%	41
Distribution channels	42,33	26,02	61,46%	39
Key activities	46,67	31,90	68,35%	39
Key assets	44,67	30,21	67,64%	35
Collaboration with partners	46,67	30,27	64,87%	37
Revenue structure	37,44	26,93	71,91%	28
Cost structure	38,89	26,78	68,87%	32

Source: Authors own work.

Table 4 shows that Value Propositions is the area most saturated with Industry 4.0 technologies. Companies are leveraging AI, Big Data, and other Industry 4.0 technologies to modernize their products and services, offering increasingly advanced functionalities, features, and personalization. In general, firms are seeking to increase competitiveness through innovation. It is worth noting, however, that the median (52) is lower than the mean, suggesting that a small group of highly advanced companies significantly inflates the overall result, while the typical company has reached only about half of the possible level of maturity. Therefore, it is important to consider the role of Industry 4.0 technologies and how they translate into innovation not only at the organizational level but also in terms of products and services. The market segmentation results indicate a shift from traditional segmentation approaches toward data-driven segmentation based on Big Data. This transition is still in progress. A mean below 50 suggests that most companies have not progressed beyond the data collection stage; although they are already able to perform Big Data analyses, they are not yet capable of automatically adapting their offerings in real time. This indicates that a broader use of AI-based tools may be necessary. It is also worth highlighting the area of key actions. The low median (39) indicates that a significant number of surveyed companies have not yet transitioned beyond “Industry 3.0.” They may be investing in modern machinery; however, two major problems remain. First, operational processes are not yet saturated with intelligent technologies, which suggests that technology is still treated mainly as a support tool rather than a driving force of transformation. Second, there is a lack of organizational readiness for change. Much more effort is needed to build awareness of digital transformation—understood not as overlaying new technologies onto old processes, but as a fundamental redesign of processes based on intelligent technologies—and to manage change effectively. If this awareness does not evolve, a paradox may emerge in which, as a civilization, we continue to develop AI technologies but attempt to fit them into outdated industrial or business structures. Therefore, further research is needed on the organization and management of Industry 4.0 technologies.

Discussion

From the perspective of the conducted research—a systematic literature review and a quantitative study—the obtained results enabled us to answer the research questions RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC? RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies? RQ3: Which Industry 4.0 technologies are most widely used in BMC? For the first question, RQ1, the research results using a systematic literature review indicate that these technologies include AI, IoT & IIoT, Cloud Computing, and also robotization and automation. From the perspective of the research results, a quantitative method based on the RQ3 survey revealed that the most widely used Industry 4.0 technologies in BMC are BD&AI, Cloud Computing, IoT & IIoT, and also cybersecurity solutions. In terms of RQ2, based on the survey results, we can identify the value proposition, customer segmentation, key activities, key partners, and key processes. The results of the systematic literature review indicate that these include: key processes, key resources, and the value proposition.

As part of the discussion, we compare the results of our study with the findings of other research. First, we compare our results with the study by Julian Marius Muller, *Business model innovation in small and medium sized enterprises. Strategies for industry 4.0 providers and users* (Müller, 2019). This article presents the results of a qualitative study aimed at examining the impact of Industry 4.0 on the business models of SMEs in the manufacturing sector. The study focused on the mechanical and machinery engineering industry, the automotive industry, and the electrical industry, as these sectors were considered the most affected by Industry 4.0. Interviews were conducted to explore changes in business models related to the adoption of Industry 4.0 technologies, with a total of 43 interviews carried out: 24 from mechanical and machinery engineering companies, 13 from automotive suppliers, and 6 from the electrical sector. The study showed that *Key Resources* were the most frequently mentioned business model component (58.14% of respondents), primarily focusing on two aspects: production facilities and equipment needing modification or purchase according to specifications, or adaptation of existing machinery, also known as “modernization”. This is a notable finding in terms of digital transformation toward Industry 4.0, as it involves applying digital solutions to analog assets. Importantly, there is alignment with our findings: in both our systematic literature review and survey-based quantitative study, *Key Resources* are among the areas with the highest concentration of Industry 4.0 technologies. The only difference is their ranking: in the literature review, *Key Resources* are second, while in the survey they are third. The *Value Proposition* is the second most frequently mentioned component (53.49% of respondents), focusing on new products, services, or combinations thereof offered to customers. Our findings confirm that *Value Proposition* is among the areas

with significant Industry 4.0 technology adoption, ranking third in the literature review and first in the quantitative survey. *Key Partners* were the third most cited component in Muller's study (48.84% of respondents), while in our survey-based study, it ranks fourth, showing a somewhat similar trend. Interestingly, Muller's study indicates that *Key Activities* were the second least frequently mentioned component (23.26% of respondents), whereas in our research, Key Activities played a significant role in the application of Industry 4.0 technologies, ranking first in the literature review and fifth in the survey, suggesting this area requires further investigation.

Next, we compared our results with those of Giuditta Pezzotta, Veronica Arioli, Federico Adrodegari, et al., in the article *The Digital Servitization of Manufacturing Sector: Evidence from a Worldwide Digital Servitization Survey* (Pezzotta et al., 2023). This study targeted managers of SMEs in the manufacturing sector, with main objectives including: (1) analyzing how manufacturing firms implement digital technologies to support the shift from a product-based business model to a service-oriented one, and (2) identifying key challenges and best practices characterizing digital transformation in manufacturing companies. Relevant to our study were the findings on the current state of Industry 4.0 technology implementation in service delivery. The authors reported the following adoption rates: IoT (50%), Cloud Computing (47%), Cybersecurity (43%), Big Data Analytics (35%), Simulation & Connected Machines (24%), AR (23%), AI/ML (20%), Advanced Manufacturing Solutions (13%), Additive Manufacturing (13%). They also identified the potential for further adoption: IoT (33%), Cloud Computing (32%), Cybersecurity (30%), Big Data Analytics (43%), Simulation & Connected Machines (43%), AR (42%), AI/ML (49%), Advanced Manufacturing Solutions (31%), Additive Manufacturing (27%). The authors note that small enterprises (26% of the sample) lag in implementing digital/intelligent technologies, mainly investing in the three most widely used technologies (IoT, Cloud Computing, Cybersecurity), while large enterprises (47%) are increasingly adopting more complex digital/intelligent technologies. Comparing these findings with our survey-based results, there is alignment in the adoption of Cloud Computing, IoT & IIoT, Cybersecurity, and BM & AI technologies (combined in our study), corresponding to Pezzotta et al.'s results prior to potential increase in Big Data Analytics (35%) and AI/ML (49%), with a total of 84%, the highest among all technologies. After this adjustment, the overall picture of Industry 4.0 technology adoption aligns with our survey results.

Other notable findings from our survey-based quantitative study include the variability of Industry 4.0 technology applications across different business model areas. Variability indices indicate heterogeneous adoption, which may result from diverse business models and corresponding technology needs. Alternatively, low digital awareness or maturity regarding Industry 4.0 applications in specific business models may limit practical implementation. These insights provide a basis for developing new hypotheses and conducting further research.

It is worth emphasizing the differences between the literature and the empirical research. The article shows that SLR clearly points to the areas of Key Activities, Key Resources, and Value Proposition as the dominant areas for Industry 4.0 technology applications. The survey, in turn, points to Value Proposition, Customer Segmentation, and Key Activities. Therefore, there is a clear agreement regarding areas such as Key Activities and Value Proposition. There is a noticeable difference between Key Resources and Customer Segmentation. The literature research indicates greater applications in the back-office, while the survey research points to the so-called front-office, i.e., Customer Segmentation. On the one hand, these differences may stem from different perspectives – the literature research focuses on conceptual applications, while enterprises implement technologies according to current needs and investment opportunities. It should be noted that conceptual research accounts for 30% of the research methods. A tempting prospect regarding key resources is the ability to adapt existing assets in conjunction with Industry 4.0 technologies, for example, within IoT and IIoT. Installing sensors to control analog devices allows for optimal use and translates into lower energy costs.

It's also worth noting that the customer groups or recipients to whom a company targets its products or services significantly impact financial results, for example, the Return on Sale (ROS) indicator. Applying Industry 4.0 technologies, particularly Big Data and Artificial Intelligence analytics, to activities such as market segmentation can contribute to better offer tailoring and price optimization, leading to increased sales and, consequently, better financial results.

The results of both the SLR and survey studies also raise the question: "Why are some technologies more prevalent in business models than others?" On the one hand, the use of technologies such as BD & AI, Cloud Computing, and IoT/IIoT is clearly noticeable, while on the other hand, the implementation of Quantum Computing and MES is low. Important factors may include business needs, the degree of implementation, process adaptability, universality, the organization's maturity to implement technology, company size, cost vs. revenue. Business needs may indicate the viability of implementing technologies that will translate into results in a given business model. Ease of implementation will contribute to the rapid implementation of technology into business processes, adaptability allows for the technology to be applied to various types of problems within a given category, and universality may indicate applications in various business areas. The organization's maturity to technology, such as acceptance vs. resistance to technological change, is also important. Company size may indicate that a large enterprise has a greater chance of using, for example, MES (Manufacturing Execution System) technology, which promotes vertical and horizontal integration and is even an essential tool for more efficient company operation. In a small or medium-sized enterprise, CRM (Customer Relationship Management), MRP (Material Requirements Planning), or ERP (Enterprise Resource Planning) may play a more important role. In turn, technology such as quantum computing can be used where very large data sets, complex simulations, or advanced research

and development projects are involved. It seems that such technology may primarily find applications in large organizations.

From the perspective of researching topics related to the application of Industry 4.0 technologies in specific BMC areas, the study results indicate a unique opportunity to create various configurations for different business models. These primarily include configurations between selected Industry 4.0 technologies. These can also include configurations in which Industry 4.0 technologies are combined with older technologies often referred to as analog. For example, the sensorization of analog devices (which have analog meters and indicators) for beverage production allows not only for digital measurement but also for data collection and analysis to optimize processes. It is clear, however, that the study results do not demonstrate the possible configuration paths for these technologies for different types of companies. However, they do indicate which areas are worth starting with specific technologies. On the one hand, at the deductive level, the study met its assumptions regarding the general results, but on the detailed level, further research is undoubtedly needed. The results of this study should be considered a map of the applications of Industry 4.0 technologies in specific BMC areas. These results can contribute to further research into specific configurations of technology implementation paths for different types of enterprises, for example, at the level of conceptual research or case study research. We believe that the research findings can also provide a reference point for Industry 4.0 technology configurators to develop proprietary technology configurations for their clients.

Conclusion

This article presents the results of two studies. The first was conducted using a systematic literature review, and the second was conducted using a quantitative survey. The results provided answers to the research questions RQ1: Can the existing research literature identify which Industry 4.0 technologies are most widely used in BMC? RQ2: In which business model elements do the surveyed companies most frequently use Industry 4.0 technologies? RQ3: Which Industry 4.0 technologies are most widely used in BMC? The research revealed that BD&AI, Cloud Computing, and IoT & IIoT are among the technologies most widely used in BMC. The areas with the highest application of Industry 4.0 technologies in BMC are: value proposition, key activities, and key resources, according to the systematic literature review and survey.

From the perspective of researching topics related to the application of Industry 4.0 technologies in specific BMC areas, the study results indicate a unique opportunity to create various configurations for different business models. These primarily include configurations between selected Industry 4.0 technologies. These can also include configurations in which

Industry 4.0 technologies are combined with older technologies often referred to as analog. For example, the sensorization of analog devices (which have analog meters and indicators) for beverage production allows not only for digital measurement but also for data collection and analysis to optimize processes. It is clear, however, that the study results do not demonstrate the possible configuration paths for these technologies for different types of companies. However, they do indicate which areas are worth starting with specific technologies. On the one hand, at the deductive level, the study met its assumptions regarding the general results, but on the detailed level, further research is undoubtedly needed. The results of this study should be considered a map of the applications of Industry 4.0 technologies in specific BMC areas. These results can contribute to further research into specific configurations of technology implementation paths for different types of enterprises, for example, at the level of conceptual research or case study research. We believe that the research findings can also provide a reference point for Industry 4.0 technology configurators to develop proprietary technology configurations for their clients.

Quantitative survey research revealed high coefficients of variation regarding the application of Industry 4.0 technologies in specific areas. Based on these results, we proposed developing research hypotheses that this state of affairs is influenced by the diversity of research business models or that it results from a low level of awareness and maturity regarding the application of Industry 4.0 technologies in specific business models, e.g., within a given industry. These hypotheses should be examined by a wider group of researchers.

The study also had limitations. In the case of the literature review, the research framework we developed focused on the use of single research methods. During data analysis, it was observed that two or even three methods were being used simultaneously to study the application of Industry 4.0 technologies in different areas of the BMC template. Another limitation of the literature study was its limited number. It is impossible to rule out the possibility that the review (search engine algorithms) did not identify publications that could be included in the literature review database. Another significant limitation was the size of the literature review database. In the case of survey studies, the natural limitation is the research sample. Other significant limitations include the level of awareness of digital transformation within organizations, which may also affect the completeness of the picture of Industry 4.0 applications in BMC within enterprises.

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