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Industry 4.0—Premise for Sustainability: Implementation Degree in Manufacturing Companies from Romania

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Abstract: Industry 4.0 cannot be understood without sustainable development, being an essential condition for ensuring market success, economic growth, and minimal environmental impact. Considering the increase in interest for applying Industry 4.0 principles by industrial companies, the aim of this paper is to find the degree and benefits of implementing the new technologies by manufacturing engineering companies from Romania. The research methodology proposes testing the opinion of top managers regarding certain Industry 4.0 issues. Data processing and analysis was conducted by means of SPSS software. The obtained results revealed that industrial companies from Romania show quite a high interest in developing all the processes from a company regarding the entire process flow, from client order to product delivery. Moreover, small and micro companies that participated in this study have recorded notable scores in respect to implementing the principles of Industry 4.0, considering their flexibility and the communication among employees, which is more efficient than in case of large and medium companies. We concluded that this study facilitates an understanding of the degree of implementing Industry 4.0 principles by Romanian manufacturing companies that stands at the base of sustainable development of businesses.

Keywords: Industry 4.0; sustainable development; benefits; degree of implementation; artificial intelligence; manufacturing

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1. Introduction

Industry 4.0, as IT integration through cyber-physical systems, can be used to solve the issues related to the increase of products and supply chain complexity [1] in order to provide flexibility for enterprise-based production systems. It has been considered a new industrial stage in which several emerging technologies converge to provide digital solutions [2]. Implementing Industry 4.0, companies must not aim only at the benefits from the perspective of the company, but also from an environmental perspective, creating a frame for sustainable development and reducing their environmental impact.

The term Industry 4.0 refers to the use of cutting-edge digital technologies to industrial machines and processes. The goal of fully integrating these technologies into the industrial setup is to maximize productivity, automation, and operational efficiency [3].

The incorporation of cutting-edge technologies into the industrial sector is the fundamental idea behind Industry 4.0 [4]. Industry 4.0, which was first discussed in Germany in 2011 when a new strategic vector known as “Plattform Industrie 4.0” was unveiled and introduced, is the next phase of the industrial revolution that has the potential to further alter production flow, communication between humans and machines, and relationships between suppliers, producers, and customers [5].

Although industry and researchers have different ideas about what Industry 4.0 is and how to define it [6–13], there is consensus on the terminology that is most frequently used in the area to describe the technologies associated with Industry 4.0. These are Big Data (BD), Cyber-Physical Systems (CPSs), Internet of Things (IoT), Artificial Intelligence (AI), Additive Manufacturing (AM), Cloud Computing, Augmented/Virtual Reality, cybersecurity, and cobots (collaborative robots). The industry will benefit from the effective integration of these technologies into business and automation processes, not only in terms of operations but also in terms of the economy and environment [5].

BD Analytics is the process of gaining insight and understanding from massive amounts of data by identifying hidden clusters and connections. This allows systematic models to be identified and improved decision-making possible [14].

A new class of technologies, CPSs combine physical and computational capabilities to communicate with people in novel ways [15]. CPSs are computers equipped with actuators and small sensor networks that are integrated into machine components, materials, and equipment established an Internet connection [16].

IoT describes the networked systems and gadgets used in everyday consumer applications, including smart home appliances, consumer electronics, and personal health monitoring equipment, while the term of "Industrial Internet of Things" (IIoT) describes the networked industrial systems and devices that assist industrial processes including supply chain and logistics, production, and quality control [17]. Security threats arise from the existence of various things that intelligently communicate with one another and transfer vast volumes of information, making cybersecurity a crucial issue for Industry 4.0 [18,19].

IoT is seen by Del Sarto et al. [20] as a frame where real, digital, and virtual dimensions meet in order to create smart environments that help many sectors to become more intelligent. The authors also highlight that IoT is found in the initial stage, and that to benefit from its advantages, companies must adopt novel thinking and ideas for conducting business. The authors of this paper develop a survey-based study to discover how companies adjust their business models to better operate in IoT environment.

AI is intelligence derived from algorithms that are supplied to computers to help them solve problems, make decisions, and carry out tasks that would normally be performed by humans [21].

Using CAD models, AM is a process for printing three-dimensional solid objects by layering one material on top of another [22]. It is expected to become a key technology driver to fabricate highly sophisticated customized products with advanced features that are otherwise not possible to produce with conventional manufacturing processes [23]. Niaki et al. [24] found that AM is adopted due to the economic motives of sustainability than the social and environmental sustainability benefits.

Cloud Computing is the term used to describe remote computing over wireless networks, in which services are seen online using scalable resources [25,26].

Another important technology is Augmented/Virtual Reality, which mixes and supports reality through the use of digital 3D models [25]. Primarily utilized in the assembly of intricate parts or as a real-time technical 3D documentation tool, it frequently supports predictive maintenance [27,28].

When people and robots are in close proximity to one another or in a shared space, a collaborative robot, also known as a cobot, is intended for direct human–robot interaction or collaboration [29]. Industrial or automated robots work with humans in automation operations inside an industrial environment.

Ferrigno et al. [13] focused their research on the relationship between technologies underlying Industry 4.0 and the business models adopted by different companies. In order to highlight this connection, the authors have developed a study based on scientific publications (a sample of 482 articles) from Scopus database between 2011 and 2022. This paper revealed important issues, such as the most relevant sources, the most cited sources, the countries that are most preoccupied with this field of interest, and others. Romania is not found in this ample study.

Analyzing and identifying the obstacles manufacturing organizations face is helpful when planning the implementation of Industry 4.0 principles. A lack of skilled personnel [30–32], a lack of management competency [14], a lack of financial resources [33], a lack of standard planning and strategy [34], and a lack of infrastructure [34,35] are the most significant obstacles to Industry 4.0 implementation that have been noted in the literature.

Barriers to Industry 4.0 adoption in manufacturing organizations have been identified and highlighted in certain research. In order to overcome some implementation obstacles and offer strategic direction for the implementation of Industry 4.0′s advanced key technologies, Khlil et al. developed a novel decision-making and implementation strategy. The analysis of barriers revealed that the top barrier was a lack of funding, a sign that businesses anticipate greater expenditure. This was followed by a lack of infrastructure and skilled workers [4].

Industry 4.0 has many benefits, including reduced labor costs, easier business procedures, fewer inventory errors, and more transparency in logistical processes (cost of logistics, delivery time, delay in transportation, inventory reduction, damage or loss, service frequency, accurate forecasting, reliability, flexibility, transport quantities, applications, and others) [36]. These are all essential for raising revenue and productivity.

Because different companies have different visions for Industry 4.0, there is not a common understanding or strategy for its implementation path [5]. Several studies have examined the challenges and issues of firms in implementing Industry 4.0. According to Mamad, the hardest things for companies to cope with are the employees' qualifications and problem-solving abilities, as well as their ability to analyze failure and adapt to changing circumstances and completely new tasks [36]. Other challenges, as some researchers stated include innovation, technological components, digital transformation advancements [17,36], handling of large amounts of data [37,38], convergence of different data standards to a uniform approach [39], high investment costs, and a lack of clarity about economic benefits and challenges in value chain integration [40].

Some studies have compared the implementation degree of Industry 4.0 in different size companies and demonstrated that, when it comes to implementing Industry 4.0, small-medium enterprises must be treated differently from large organizations since they are less equipped to handle the financial, technological, and manpower issues that come with it [41–43]. The fact that the small and medium-sized business sector is still hesitant to invest in new technology in order to enhance its production and logistics system was highlighted by Dossou et al. [44].

Cotrino et al. stated that the majority of large businesses are digitizing their supply chains, customer services, and financial systems, and they have a plan in place for digital transformation and Industry 4.0 technology adoption. Additionally, the research results showed that the small-medium enterprises do not have the economic resources for implementing Industry 4.0 technologies [45].

To date, few studies have analyzed the degree and benefits of implementing principles of Industry 4.0 by Romanian companies from manufacturing industry.

A rise in the need for human resources skills is one of the implications of Industry 4.0, according to Marinas et al., which studied the Romanian example of the European manufacturing sector transition toward digital technology [46].

Türkeș et al. highlighted in their research that Romania is fully transitioning from Industry 2.0 to Industry 4.0 and there is a desire to implement Industry 4.0 technology in small-medium enterprises [14].

Literature supply researches regarding the connection between Industry 4.0 and sustainability. Thus, Brozzi et al. [47] analyzes the impact of Industry 4.0 upon environment in case of certain manufacturing companies from Italy upon the environment. Their research showed that economic interests of the companies prevail.

Working together to address sustainability concerns and Industry 4.0 can have several benefits, including knowledge sharing, economies of scale, equitable cost sharing, professional experience, and industry-specific data interchange and storage [48].

The Industry 4.0 and Sustainable Development Goals (SDGs) are concurrent, as stated by Islam et al. [49].

The similarities between Industry 4.0 and sustainability are highlighted by Beltrami et al. [50], specifically the impact of Industry 4.0 technologies on sustainability results and practices.

Kahn et al. conducted an overview upon studies developed by researchers from all over the world regarding Industry 4.0 and sustainable development [51]. The authors presented interesting information about how gaining social, economic, and environmental benefits through sustainable growth in an Industry 4.0 framework supports circular economic aims. The research was conducted over an 8-year time period, searched five of the most relevant databases from the field, and discussed 4291 papers. This study showed an increased preoccupation of companies and authors about Industry 4.0 in the context of sustainability after 2018. The industrial field most concerned with Industry 4.0 sustainability was the manufacturing sector. The research revealed that the most publications in the field of Industry 4.0 and sustainability come from Spain, India, and Brazil. No Romanian authors are found in this study, nor is Romania. This is the main reason that our research was focused on manufacturing companies from Romania.

Hence, this research is useful for understanding the degree of implementation, as well as the benefits in production efficacy and competitiveness in case of companies from Romania in manufacturing engineering field.

The novelty of this study is related to the following aspects: (i) the implementation degree of Industry 4.0 principles in Romanian manufacturing companies, considering different types of capital and the number of employees; (ii) identifying some connections between Industry 4.0 and certain benefits (increase in productivity, improvement of products quality, a better employees' satisfaction, better working conditions, increase of the profit).

An infographic diagram that presents some aspects related to the present research can be seen in Figure 1.

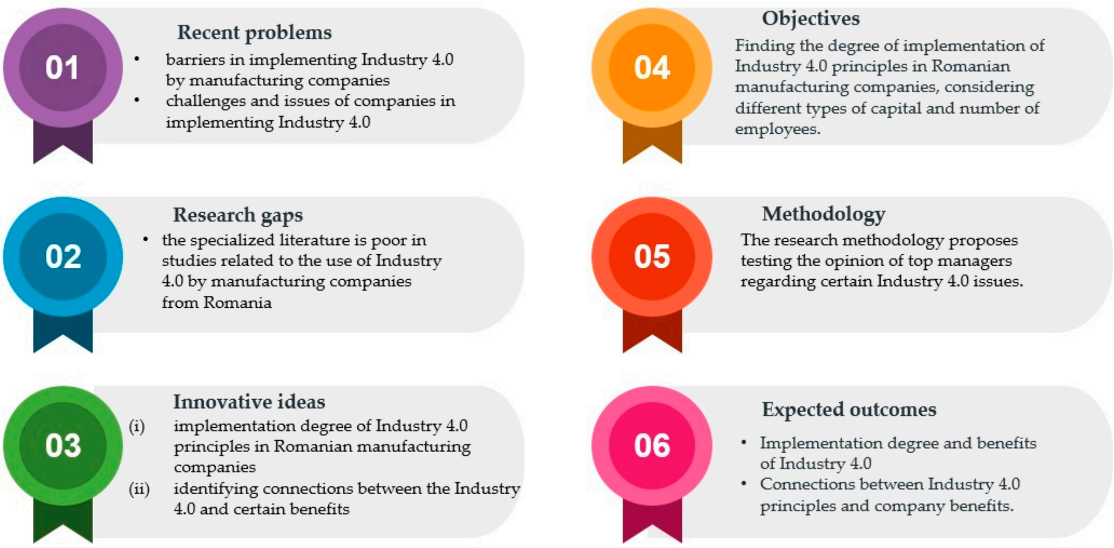

Figure 1. Infographic diagram of the present research.

2. Materials and Methods

This paper is based on a study conducted between 15 April and 15 October 2023. The main objective is to find the degree of implementation of Industry 4.0 principles in Romanian manufacturing companies, considering different types of capital and number of employees.

2.1. Research Method

The market study presented in this paper was conducted by survey, a method considered by many theoreticians and practitioners as one of the most efficient available [52,53]. The method was based on a questionnaire as the tool for data collection, and a sample representative for the population as a whole. The structured questionnaire used in the study consisted of a set of 24 questions arranged by a fixed interview scheme. The questionnaire was structured in four sections, as follows: the first section, containing questions 1 to 15, referred to the degree of implementing the principles of Industry 4.0 by Romanian industrial companies. The second section, containing questions 16 to 20, referred to the advantages gained by the companies that have implemented principles of Industry 4.0. The third section is the identification for the companies included in the sample, and the fourth section required the companies' accept for data publishing. All the questions are close-ended. Two questions are binary answer based, 19 questions are orderly scaled, and 3 questions offer a simple choice scale. The questionnaire is presented in Appendix A. Although at present surveys are one of the most frequently utilized method, it is unlikely that they are free of errors as to data collection, processing, and analysis. In order to reduce the number and effects of such inherent errors, the authors have taken into consideration the following aspects: avoiding random sampling by the exact calculation of the sample based on a mathematical equation and correction of the sample by the population size, namely the total number of Romanian companies acting in the field of Manufacturing Engineering; asking respondents from top management of the companies to answer the question; including companies of all the types, regarding the capital, the number of employees and the region of the country; utilization of close-ended questions and standard scales.

2.2. Participants

The size (n) of the representative sample was determined by Equation (1):

$$n = \frac{z^2 \cdot p \cdot q}{E^2} = 384 \text{ companies} \quad (1)$$

where: z^2 is the square of the coefficient corresponding to the considered level of confidence (95%); p is the estimation of percentage for success; q is the estimation of percentage for failure; E^2 is the square of admitted error, expressed in percentages.

The size of the above determined sample has to be corrected by the total population size. As specified before, the total population size (N) is the number of industrial companies from Romania acting in the field of manufacturing. The corrected sample size (n_c) is given by Equation (2):

$$n_c = \frac{N \cdot n}{N + n} = 304 \text{ companies} \quad (2)$$

The main problem faced by the authors of this paper were the difficulties encountered in obtaining responses from the subjects and the long period of time over which the responses were collected, considering the modality of the questionnaire dissemination, namely by e-mail and utilization of Google Docs tools.

The response rate was quite good: of 304 company managers, 264 responded but four of them did not agree to publish the results, even if the results were confidential and the respondents were anonymous. For this reason, these 4 companies were excluded from this research. The final sample was 260 companies from Romania, acting in the field of manufacturing engineering.

The flow diagram of the research is presented in Figure 2.

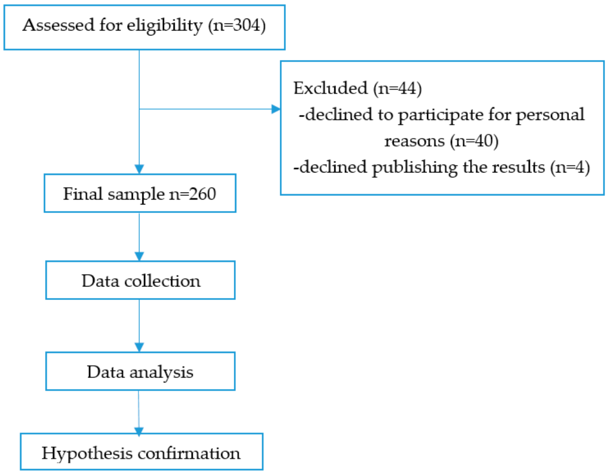

Figure 2. The flow chart of the experimental methodology.

2.3. Statistical Analyses

Data processing and analysis was conducted by means of SPSS Statistics for Windows (version 20.0, IBM Corp., Armonk, NY, USA) using different methods, such as: frequency tables, correlations, ANOVA, etc. The association between variables was performed using Spearman correlation coefficient (ρ). Correlation values above 0.8 were considered very strong, between 0.6 and 0.79 strong, between 0.4 and 0.59 moderate, weak for values between 0.2 and 0.39, and below 0.19 very weak [54]. The significance level for all comparisons and correlations was $p < 0.05$.

Considering the previous mentioned studies [4,13,17,20,28–51] and based on the fact that the specialized literature is poor in studies related to the use of Industry 4.0 by manufacturing companies from Romania, the research developed in this paper was based on certain hypotheses, as follows.

H_1: *There is a connection between the implementation of Industry 4.0 principles by the Romanian companies from the field of Manufacturing Engineering and the following aspects: increase in productivity, improvement of products quality, better employees' satisfaction, better working conditions, increase of the profit*.

H_2: *There are certain differences among companies regarding the implementation of Industry 4.0 principles in respect with the type of capital*.

H_3: *There are certain differences among companies regarding the implementation of Industry 4.0 principles in respect with the number of employees*.

H_4: *There are differences among companies regarding obtaining certain benefits (increase in productivity, improvement of products quality, better employees' satisfaction, better working conditions, increase of the profit) in respect with the type of capital.*

H_5: *There are differences among companies regarding obtaining certain benefits (increase in productivity, improvement of products quality, better employees' satisfaction, better working conditions, increase of the profit) in respect with the number of employees.*

3. Results

As mentioned in Section 2 of this paper, the SPSS software tool was used for data processing and analysis. For validating or invalidating the hypotheses, specific coefficients must be calculated and statistic tests have to be performed. The main results of this research are presented as follows.

Table 1 highlights the percentage of companies that have implemented certain Industry 4.0 principles.

Table 1. Analysis of variable Q1.

Q1	Frequency	Percent
No	8	3.1
Yes	252	96.9
n	260	100

n—sample size.

Figure 3 indicates the scores calculated by SPSS software in respect to the implementation the principles of Industry 4.0 by the companies (blue color) and with the obtained benefits (yellow color).

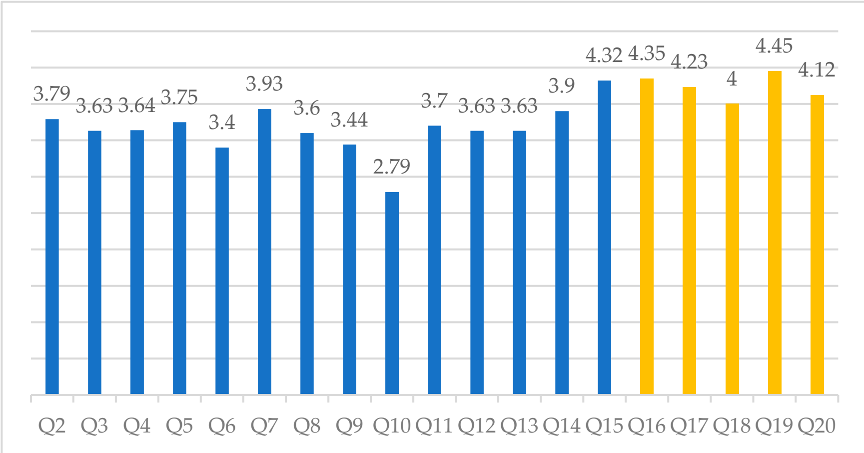

Figure 3. Scores of implementing the principles of Industry 4.0 by companies and their benefits.

In respect with hypothesis H_1, it can be tested by considering variables Q2–Q15 and Q16–Q20, from Appendix A. Because these variables are ordinally scaled, the connection of such variables is given by the Spearman Coefficient [55,56]. This connection is shown in Table 2. The considered number of responses for these variables is 252, as results from Table 1. Table 2 presents the connections between variables that represent the degree of implementation of Industry 4.0 principles (Q2–Q15) and the variables that express the benefits of implementing them (Q16–Q20).

Table 2. Testing hypothesis H_1.

Variable	Parameters	Q16	Q17	Q18	Q19	Q20
Q2	ρ	0.116	0.189	−0.122	0.014	0.107
	p	0.066	0.003	0.053	0.826	0.09
Q3	ρ	0.287	0.182	−0.093	0.026	0.158
	p	≤0.001	0.004	0.142	0.684	0.012
Q4	ρ	0.280	0.167	0.174	0.187	0.291
	p	≤0.001	0.008	0.006	0.003	≤0.001
Q5	ρ	0.329	0.199	0.136	0.340	0.257
	p	≤0.001	≤0.001	0.031	≤0.001	≤0.001
Q6	ρ	0.207	0.177	−0.065	−0.061	0.151
	p	≤0.001	0.005	0.307	0.337	0.016
Q7	ρ	0.336	0.352	0.172	0.257	0.217
	p	≤0.001	≤0.001	0.006	≤0.001	≤0.001
Q8	ρ	0.071	0.107	−0.141	0.109	0.053
	p	0.261	0.090	0.025	0.084	0.401

Table 2. *Cont.*

Variable	Parameters	Q16	Q17	Q18	Q19	Q20
Q9	ρ	0.099	−0.059	−0.084	0.026	0.069
	p	0.119	0.350	0.186	0.685	0.275
Q10	ρ	0.244	0.255	0.116	0.135	0.234
	p	≤0.001	≤0.001	0.067	0.032	≤0.001
Q11	ρ	0.003	0.123	0.138	0.249	0.247
	p	0.957	0.051	0.028	≤0.001	≤0.001
Q12	ρ	0.393	0.359	0.025	0.224	0.319
	p	0.000	0.000	0.694	0.000	0.000
Q13	ρ	0.237	0.095	0.024	0.197	0.074
	p	0.000	0.133	0.707	0.002	0.244
Q14	ρ	0.183	0.142	0.043	0.207	0.243
	p	0.004	0.024	0.496	0.001	0.000
Q15	ρ	0.272	0.225	−0.001	0.216	0.260
	p	0.000	0.000	0.985	0.001	0.000

ρ—Spearman correlation coefficient, *p*—significant level of probability.

In order to find certain differences among companies regarding the implementation of Industry 4.0 principles in respect with the type of capital (Hypothesis H_2), ANOVA analysis was performed. The results are presented in Table 3.

Table 3. ANOVA for testing hypothesis H_2.

Variable	Type of Capital	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q2	Romanian	74	3.36	0.959	3.14	3.59	≤0.001
	Foreign	128	3.92	0.838	3.78	4.07	
	Mixed	50	4.06	0.740	3.85	4.27	
	Total	252	3.79	0.898	3.67	3.90	
Q3	Romanian	74	3.49	1.263	3.19	3.78	0.232
	Foreign	128	3.64	1.148	3.44	3.84	
	Mixed	50	3.84	0.817	3.61	4.07	
	Total	252	3.63	1.130	3.49	3.78	
Q4	Romanian	74	3.74	0.845	3.55	3.94	0.240
	Foreign	128	3.65	0.944	3.48	3.81	
	Mixed	50	3.46	0.952	3.19	3.73	
	Total	252	3.64	0.919	3.52	3.75	
Q5	Romanian	74	3.55	1.207	3.27	3.83	0.121
	Foreign	128	3.84	0.926	3.68	4.01	
	Mixed	50	3.80	0.700	3.60	4.00	
	Total	252	3.75	0.984	3.63	3.87	
Q6	Romanian	74	3.28	1.104	3.03	3.54	0.049
	Foreign	128	3.54	0.783	3.40	3.68	
	Mixed	50	3.22	0.910	2.96	3.48	
	Total	252	3.40	0.920	3.29	3.51	
Q7	Romanian	74	3.69	1.215	3.41	3.97	0.066
	Foreign	128	3.98	1.283	3.75	4.20	
	Mixed	50	4.18	0.800	3.95	4.41	
	Total	252	3.93	1.191	3.78	4.08	
Q8	Romanian	74	3.23	1.028	2.99	3.47	≤0.001
	Foreign	128	3.77	1.023	3.59	3.94	
	Mixed	50	3.74	0.899	3.48	4.00	
	Total	252	3.60	1.026	3.48	3.73	

Table 3. *Cont.*

Variable	Type of Capital	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q9	Romanian	74	2.93	1.064	2.69	3.18	≤0.001
	Foreign	128	3.77	0.943	3.60	3.93	
	Mixed	50	3.34	1.062	3.04	3.64	
	Total	252	3.44	1.064	3.30	3.57	
Q10	Romanian	74	2.09	1.088	1.84	2.35	≤0.001
	Foreign	128	3.08	1.098	2.89	3.27	
	Mixed	50	3.10	1.216	2.75	3.45	
	Total	252	2.79	1.203	2.64	2.94	
Q11	Romanian	74	3.69	1.158	3.42	3.96	0.89
	Foreign	128	3.68	0.878	3.53	3.83	
	Mixed	50	3.76	1.117	3.44	4.08	
	Total	252	3.70	1.012	3.57	3.82	
Q12	Romanian	74	3.08	1.044	2.84	3.32	≤0.001
	Foreign	128	3.88	1.004	3.70	4.05	
	Mixed	50	3.80	0.926	3.54	4.06	
	Total	252	3.63	1.058	3.50	3.76	
Q13	Romanian	74	3.23	1.458	2.89	3.57	≤0.001
	Foreign	128	3.86	1.033	3.68	4.04	
	Mixed	50	3.62	0.987	3.34	3.90	
	Total	252	3.63	1.193	3.48	3.77	
Q14	Romanian	74	3.59	0.826	3.40	3.79	≤0.001
	Foreign	128	4.02	0.808	3.88	4.16	
	Mixed	50	4.02	0.769	3.80	4.24	
	Total	252	3.90	0.826	3.79	4.00	
Q15	Romanian	74	4.03	0.860	3.83	4.23	≤0.001
	Foreign	128	4.48	0.676	4.37	4.60	
	Mixed	50	4.34	0.626	4.16	4.52	
	Total	252	4.32	0.749	4.23	4.41	

N—number of respondents, X—average, SD—standard deviation, CI—interval of confidence, *p*—significant level of probability.

For testing the hypothesis H_3, the results of ANOVA analysis are presented in Table 4, where differences among companies in respect with the number of employees regarding the implementation of Industry 4.0 principles can be seen.

Table 4. ANOVA for testing hypothesis H_3.

Variable	Number of Employees	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q2	1–9 employees	13	2.62	0.768	2.15	3.08	≤0.001
	10–49 employees	49	3.49	0.582	3.32	3.66	
	50–249 employees	70	3.73	0.833	3.53	3.93	
	over 249 employees	120	4.07	0.914	3.90	4.23	
	Total	252	3.79	0.898	3.67	3.90	
Q3	1–9 employees	13	2.15	1.405	1.30	3.00	≤0.001
	10–49 employees	49	3.92	0.731	3.71	4.13	
	50–249 employees	70	3.77	0.920	3.55	3.99	
	over 249 employees	120	3.60	1.226	3.38	3.82	
	Total	252	3.63	1.130	3.49	3.78	

Table 4. *Cont.*

Variable	Number of Employees	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q4	1–9 employees	13	3.54	0.967	2.95	4.12	0.088
	10–49 employees	49	3.94	0.827	3.70	4.18	
	50–249 employees	70	3.59	0.732	3.41	3.76	
	over 249 employees	120	3.56	1.027	3.37	3.74	
	Total	252	3.64	0.919	3.52	3.75	
Q5	1–9 employees	13	2.46	1.854	1.34	3.58	≤0.001
	10–49 employees	49	3.96	0.735	3.75	4.17	
	50–249 employees	70	3.84	0.895	3.63	4.06	
	over 249 employees	120	3.75	0.901	3.59	3.91	
	Total	252	3.75	0.984	3.63	3.87	
Q6	1–9 employees	13	2.00	1.155	1.30	2.70	≤0.001
	10–49 employees	49	3.67	0.718	3.47	3.88	
	50–249 employees	70	3.30	0.805	3.11	3.49	
	over 249 employees	120	3.50	0.898	3.34	3.66	
	Total	252	3.40	0.920	3.29	3.51	
Q7	1–9 employees	13	3.00	1.155	2.30	3.70	≤0.001
	10–49 employees	49	4.43	0.866	4.18	4.68	
	50–249 employees	70	4.29	0.935	4.06	4.51	
	over 249 employees	120	3.63	1.297	3.39	3.86	
	Total	252	3.93	1.191	3.78	4.08	
Q8	1–9 employees	13	2.38	0.506	2.08	2.69	≤0.001
	10–49 employees	49	3.57	0.577	3.41	3.74	
	50–249 employees	70	3.47	0.863	3.27	3.68	
	over 249 employees	120	3.83	1.186	3.61	4.04	
	Total	252	3.60	1.026	3.48	3.73	
Q9	1–9 employees	13	2.00	1.080	1.35	2.65	≤0.001
	10–49 employees	49	3.63	0.883	3.38	3.89	
	50–249 employees	70	3.33	0.880	3.12	3.54	
	over 249 employees	120	3.58	1.113	3.37	3.78	
	Total	252	3.44	1.064	3.30	3.57	
Q10	1–9 employees	13	1.46	0.967	0.88	2.05	≤0.001
	10–49 employees	49	2.73	1.095	2.42	3.05	
	50–249 employees	70	2.63	1.066	2.37	2.88	
	over 249 employees	120	3.06	1.239	2.83	3.28	
	Total	252	2.79	1.203	2.64	2.94	
Q11	1–9 employees	13	4.62	0.768	4.15	5.08	≤0.001
	10–49 employees	49	4.04	0.978	3.76	4.32	
	50–249 employees	70	3.49	1.151	3.21	3.76	
	over 249 employees	120	3.58	0.875	3.43	3.74	
	Total	252	3.70	1.012	3.57	3.82	
Q12	1–9 employees	13	2.15	1.405	1.30	3.00	≤0.001
	10–49 employees	49	3.35	0.694	3.15	3.55	
	50–249 employees	70	3.51	1.018	3.27	3.76	
	over 249 employees	120	3.97	0.987	3.79	4.15	
	Total	252	3.63	1.058	3.50	3.76	
Q13	1–9 employees	13	1.31	0.630	0.93	1.69	≤0.001
	10–49 employees	49	4.02	0.989	3.74	4.30	
	50–249 employees	70	3.74	1.247	3.45	4.04	
	over 249 employees	120	3.65	1.001	3.47	3.83	
	Total	252	3.63	1.193	3.48	3.77	

Table 4. *Cont.*

Variable	Number of Employees	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q14	1–9 employees	13	3.46	0.519	3.15	3.78	≤0.001
	10–49 employees	49	4.24	0.560	4.08	4.41	
	50–249 employees	70	3.99	0.876	3.78	4.19	
	over 249 employees	120	3.75	0.862	3.59	3.91	
	Total	252	3.90	0.826	3.79	4.00	
Q15	1–9 employees	13	3.62	1.044	2.98	4.25	0.004
	10–49 employees	49	4.29	0.645	4.10	4.47	
	50–249 employees	70	4.41	0.712	4.24	4.58	
	over 249 employees	120	4.36	0.742	4.22	4.49	
	Total	252	4.32	0.749	4.23	4.41	

N—number of respondents, X—average, SD—standard deviation, CI—interval of confidence, *p*—significant level of probability.

The ANOVA results for testing hypothesis H_4 are presented in Table 5. The differences identified related to the benefits considered by the companies after implementing Industry 4.0 principles, in respect with the type of capital are significant for the variables Q16-Q19 ($p < 0.05$).

Table 5. ANOVA for testing hypothesis H_4.

Variable	Type of Capital	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q16	Romanian	74	4.41	0.547	4.28	4.53	0.021
	Foreign	128	4.23	0.871	4.07	4.38	
	Mixed	50	4.56	0.644	4.38	4.74	
	Total	252	4.35	0.755	4.25	4.44	
Q17	Romanian	74	4.16	0.524	4.04	4.28	0.006
	Foreign	128	4.16	0.855	4.01	4.31	
	Mixed	50	4.52	0.505	4.38	4.66	
	Total	252	4.23	0.721	4.14	4.32	
Q18	Romanian	74	4.15	0.806	3.96	4.34	0.009
	Foreign	128	3.82	1.068	3.63	4.01	
	Mixed	50	4.24	0.797	4.01	4.47	
	Total	252	4.00	0.961	3.88	4.12	
Q19	Romanian	74	4.54	0.528	4.42	4.66	0.002
	Foreign	128	4.30	0.828	4.16	4.45	
	Mixed	50	4.68	0.513	4.53	4.83	
	Total	252	4.45	0.709	4.36	4.54	
Q20	Romanian	74	4.19	0.541	4.06	4.31	0.114
	Foreign	128	4.02	0.891	3.87	4.18	
	Mixt	50	4.26	0.664	4.07	4.45	
	Total	252	4.12	0.764	4.02	4.21	

N—number of respondents, X—average, SD—standard deviation, CI—interval of confidence, *p*—significant level of probability.

Table 6 presents the ANOVA result for testing hypothesis H_5, namely the differences related to the benefits considered by the companies after implementing Industry 4.0 principles, identified among manufacturing companies depending on the number of employees.

Table 6. ANOVA for testing hypothesis H_5.

Variable	Number of Employees	N	X	SD	CI95% Lower	CI95% Upper	*p*
Q16	1–9 employees	13	4.54	0.660	4.14	4.94	0.018
	10–49 employees	49	4.31	0.508	4.16	4.45	
	50–249 employees	70	4.56	0.629	4.41	4.71	
	over 249 employees	120	4.22	0.881	4.06	4.38	
	Total	252	4.35	0.755	4.25	4.44	
Q17	1–9 employees	13	4.38	0.768	3.92	4.85	0.319
	10–49 employees	49	4.14	0.408	4.03	4.26	
	50–249 employees	70	4.34	0.562	4.21	4.48	
	over 249 employees	120	4.18	0.879	4.02	4.34	
	Total	252	4.23	0.721	4.14	4.32	
Q18	1–9 employees	13	4.46	1.050	3.83	5.10	0.004
	10–49 employees	49	4.10	0.743	3.89	4.32	
	50–249 employees	70	4.21	0.931	3.99	4.44	
	over 249 employees	120	3.78	1.006	3.60	3.97	
	Total	252	4.00	0.961	3.88	4.12	
Q19	1–9 employees	13	4.77	0.599	4.41	5.13	0.017
	10–49 employees	49	4.53	0.504	4.39	4.68	
	50–249 employees	70	4.57	0.527	4.45	4.70	
	over 249 employees	120	4.31	0.848	4.16	4.46	
	Total	252	4.45	0.709	4.36	4.54	
Q20	1–9 employees	13	4.62	0.768	4.15	5.08	0.067
	10–49 employees	49	4.20	0.456	4.07	4.33	
	50–249 employees	70	4.06	0.508	3.94	4.18	
	over 249 employees	120	4.07	0.950	3.89	4.24	
	Total	252	4.12	0.764	4.02	4.21	

N—number of respondents, X—average, SD—standard deviation, CI—interval of confidence, *p*—significant level of probability.

4. Discussion

This study investigates the degree of implementing principles of Industry 4.0 by Romanian companies from the field of manufacturing industry and their benefits.

The results of using certain statistical tools for testing the hypotheses presented in Section 2 are discussed as follows.

As Table 1 presents, a high percentage (96.9%) of Romanian manufacturing companies have implemented certain principles of Industry 4.0.

As Figure 3 shows, the highest score (4.32) was obtained for variable Q15 (high performance software system for cybernetic safety), while the lowest score (2.79) is obtained by Q10 (the use of: AI, robotics, IoT, augmented reality). In respect to the benefits, the companies considered that the implementation of Industry 4.0 principles had a positive impact, especially on the working conditions (4.45) and productivity (4.35).

For testing Hypothesis H_1, Table 2 presents the Spearman coefficients that show the correlations between ordinal variables, which are statistically significant for a significant level of probability ($p < 0.05$). These correlations are presented as follows:

- The use of a software system for process monitoring, from client order to product delivery (Q2), led to product quality improvement (Q17).
- The use of Internet/Intranet for transmitting the information regarding the manufacturing flow to the employees in real time (Q3) and implementing a manufacturing management software that allows the interconnection of productive resources with the non-productive ones (Q6) led to: productivity increase (Q16), product quality improvement (Q17), and profit increase (Q20).
- The use of smart devices by the employees (Q4), implementing a manufacturing management software (Q5), and the use of a software system that automatically

transmits the information from product design to manufacturing (Q7) allow companies to gain all the advantages considered in this study.

- Implementing a manufacturing management software that allows the interconnection of productive resources with the non-productive ones (Q6) led to productivity increase (Q16), product quality improvement (Q17) and profit increase (Q20), while the use of a software system that allows the integration of process plan with manufacturing (Q8) led to a better employees' motivation (Q18).
- Even if companies have implemented a certain level of automation and robotics (a score of 3.44, as Figure 3 presents), none of the benefits considered in this research has been achieved. This principle is expressed by variable Q9.
- Even if the score is quite small (2.79), as Figure 3 highlights, the use of certain concepts specific to Industry 4.0 (as AI, robotics, IoT), given by variable Q10 allowed companies to achieve certain benefits: productivity increase (Q16), product quality improvement (Q17), better working conditions (Q19), and profit increase (Q20). The same benefits were achieved in case of the following issues: the use of a software system that alerts when the material resources inventory has reached the alert level (Q12), a flexible structure of the company (Q14) and a high performance software system for cybernetic security (Q15).
- A high transparency level regarding the operations from the company (Q11) led to: better employee motivation (Q18), better working conditions (Q19) and profit increase (Q20) and the use of a software system that automatically detects the machines, equipment failure (Q13) led to productivity increase (Q16) and better working conditions (Q19).

For testing hypothesis H2, Table 3 presents the results of ANOVA analysis. A significant level of probability p, less than 0.05, highlights that there are differences among companies regarding the implementation of certain principles of Industry 4.0 in respect with their capital. Hypothesis H_2 is confirmed in case of the following variables:

- Companies that make the most use of a software system for process monitoring, from client order to product delivery (Q2), and those that make the most use of artificial intelligence, robotics, Internet of Things, augmented reality (Q10) have mixed capital. Companies using such systems, to the least extent, have Romanian capital.
- Statistically significant differences were also recorded in respect to the following systems: software system that allows the interconnection of process plan with manufacture (Q8), software system that alerts when the inventory of material resources has reached the alert level (Q12), software system that automatically detects the machines, equipment failure (Q13), and high performance software system for cybernetic security (Q15). These systems are used to the highest degree by companies with foreign capital and to the lowest degree by companies with Romanian capital.
- Companies that have obtained the highest score in respect to a software system for manufacturing management that allows the interconnection of productive resources with non-productive ones (Q6) are companies with foreign capital and the lowest score was obtained in case of companies having mixed capital.

Hypothesis H_2 was disproved in case of variables Q3, Q4, Q5, Q7, and Q11.

For testing hypothesis H_3, ANOVA analysis was performed and the results are presented in Table 4. Hypothesis H_4 was confirmed in case of all analyzed variables ($p < 0.05$), except for variable Q4.

- Big companies (more than 249 employees) have obtained the highest score in respect with the following variables: Q2 (process monitoring from client order to product delivery), Q8 (integration of process plan with manufacturing), Q10 (artificial intelligence, robotics, Internet of Things, augmented reality), and Q12 (system that alerts when the inventory of material resources has reached the alert level).
- Notable results were obtained in the case of small sized companies (10–49 employees), who obtained the highest score in case of the following variables: Q3 (Internet/Intranet for transmitting information regarding manufacturing process in real time), Q5 (in-

terconnection of productive resources), Q6 (interconnection of productive resources with the non-productive ones), Q7 (automated transmission of information from product design to manufacturing), Q9 (automation and robotics), Q13 (system that automatically detects the machines, equipment failure), and Q14 (flexibility).

- Medium sized companies (50–249 employees) use at the highest performant software system for cybernetic security (Q15) and micro companies (less than 10 employees) have the highest level of transparency (Q11). Micro companies have obtained the least scores in respect with the other variables.

For testing hypothesis H_4, the results of ANOVA analysis are presented in Table 5. This hypothesis is confirmed in case of all variables considered ($p < 0.05$), except for variable Q20.

- The benefits of implementing the principles of Industry 4.0: an increase of productivity (Q16), improvement of product quality (Q17), a better employees' motivation (Q18), and better working conditions (Q19) are mostly obtained by companies having mixed capital, followed by companies with Romanian capital and then by companies with foreign capital. In the case of Q17, the score obtained in case of companies with Romanian capital is equal to the score of companies with foreign capital.

For testing hypothesis H_5, ANOVA analysis was performed and the results are indicated in Table 6. Hypothesis H_5 is confirmed in case of variables Q16, Q18 and Q19 ($p < 0.05$).

- Increase of productivity was mostly obtained by medium companies (50–249 employees) and a better employees' motivation and better working conditions were obtained by micro enterprises (1–9 employees).

Table 7 presents the relevant results related to the proposed hypothesis.

Table 7. Hypothesis confirmation.

Hypothesis	Confirmation	Observation
H_1	Yes	
H_2	Yes	- disproved for Q3, Q4, Q5, Q7, and Q11
H_3	Yes	- not confirmed for Q4
H_4	Yes	- not confirmed for Q20
H_5	Yes	- confirmed in case of variables Q16, Q18 and Q19

The results obtained in Section 2 showed that the objective of the present research was achieved, indicating the level of implementing the principles of Industry 4.0 by industrial companies from Romania, acting in the field of Manufacturing Engineering and the benefits of implementation. These results consist an important premise for paying a special attention to a sustainable development, considering the three pylons: economic growth, society, and environment.

5. Conclusions

The goal of this current study was to determine the extent to which Romanian manufacturing enterprises were applying Industry 4.0 concepts and the benefits obtained by implementing those concepts in order to establish critical premises for sustainability.

The research was conducted by means of inquiry method, based on two instruments: a questionnaire for a data collection and SPSS software for data processing and analysis.

Considering the previous presented results, the following conclusions could be drawn:

- The main principles of Industry 4.0 are implemented by the industrial companies from Romania, acting in the manufacturing engineering field, which could generate solid tracks for sustainable manufacturing, as some researchers [13,47,50,51] have pointed out.
- The degree of implementing the principles of Industry 4.0 is not very high (most of the scores are between 3 and 4, measured on ordinal scales where 5 is fully implemented and 1 is not at all implemented). This result is consistent with the work presented in paper [14], which presented drivers and barriers of the Romanian companies while they are fully transitioning from Industry 2.0 to Industry 4.0.
- According to the research presented in [13,36], many benefits come with Industry 4.0 and industrial companies from Romania have gained several advantages by implemented certain principles of industry 4.0. The scores obtained in case of these advantages are over 4 (measured on ordinal scales, where 5 is totally agreed and 1 totally disagreed). Such high scores indicate that industrial companies from Romania, acting in the manufacturing engineering field go into the right direction towards achieving, in the near future, good results in respect with sustainable development. There are significant differences regarding the implementation of Industry 4.0 taking into consideration variables such as: capital of the company and number of employees. Most of the companies that implemented the Industry 4.0 principles have foreign and mixed capital and are small sized companies (10–49 employees) and large companies (over 240 employees). Previous studies [41–43], considered the need to address separately small-medium enterprises and large organizations in implementing Industry 4.0 principles.
- The benefits of implementing those principles are gained mostly by companies with mixed and Romanian capital and surpassingly by small and micro enterprises. These results are surprising considering some studies [44,45], which showed that the small and medium-sized companies are not ready or do not have enough economic resources to implement Industry 4.0.

The results obtained show that industrial companies from Romania are interested in developing all the processes from a company regarding the entire process flow, from client order to product delivery. Romania is at the beginning of Industry 4.0 implementation and medium scores and weak connections between certain variables highlight that companies from manufacturing engineering from Romania do not have a very good grip on new technologies and knowhow, but there are premises for development.

Also, the obtained findings revealed that small and micro companies have recorded notable scores in respect with implementing principles of Industry 4.0, considering their flexibility and the communication among employees which is more efficient than in case of large and medium companies.

For fully benefitting from the advantages of Industry 4.0 principles and for a better exploitation of the new technology in the direction of a sustainable development, manufacturing companies from Romania need: high investments in technology; a better flexibility of the structure of the company; employees' education regarding the use of the new technology; understanding and patience of managers in respect with older employees who might be anxious and afraid of failing in using new technology; arranging seminars and workshops for employees to get acquainted of the new technology and learn and understand their benefits; education of managers and employees in the spirit of sustainability, in order to be aware of the importance of using such new and modern technologies that create high quality products, reduce waste and energy consumption, and, generally speaking, having a minimum environmental impact, to ensure the best condition for the companies, clients, society and the generations to come.

The final conclusion might be related to the contributions of this paper to the development of the existing body of literature in the field of Industry 4.0. Since literature is poor in research regarding the implementation of Industry 4.0 principles by companies from Romania, this paper presents contributions to enrichment of the field of Industry

4.0. By the means of an original survey, based on an original designed questionnaire, as an instrument for data collection, the research presented in this paper has measured the degree of implementing Industry 4.0 principles by industrial companies from Romania acting in the manufacturing engineering field, being as one the most important economic sector in Romania. The study has also revealed certain benefits obtained by the companies after implementing certain principles. The obtained results could represent a solid base for future and more detailed studies.

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Appendix A

Table A1. Questionnaire.

	Section 1
Q1	Have you implemented principles of Industry 4.0 in the company you run? Yes No
Q2 *	Software system for process monitoring, from client order to product deliver.
Q3 *	Information flow regarding manufacturing process is transmitted to the employees in real time by means of Internet/Intranet.
Q4 *	Employees have intelligent devices (tablets, mobile phones, mini laptops, etc.) that allow them to be online and permanently connected to the monitoring software system.
Q5 *	Software system for manufacturing management that allow the interconnection of productive resources: machines, equipment, people, tools.
Q6 *	Software system for manufacturing management that allows the interconnection of productive resources with the non-productive ones (quality control, purchasing management, maintenance, etc.).
Q7 *	Software system that allows the automated transmission of information from product design to manufacturing.
Q8 *	Software system that allows integration of process plan with manufacturing.
Q9 *	High level of automation and robotics in respect with manufacturing.
Q10 *	Company uses: artificial intelligence, robotics, Internet of Things, augmented reality.
Q11 *	High transparency level that allows a good visibility over the whole operations in order to make the decisional process more efficient.
Q12 *	Software system that alerts when the inventory of material resources (raw material, billets, components, finished goods) has reached the alert level.
Q13 *	Software system that automatically detects the machines, equipment failure.
Q14 *	The company structure is flexible and allows reconfigurable arrangements.
Q15 *	High performance software system for cybernetic safety.

Table A1. *Cont.*

	Section 2
Q16 **	Industry 4.0 principles implementation allowed increase in productivity.
Q17 **	Industry 4.0 principles implementation allowed product quality improvement.
Q18 **	Industry 4.0 principles implementation allowed a better employees satisfaction.
Q19 **	Industry 4.0 principles implementation allowed better working conditions.
Q20 **	Industry 4.0 principles implementation allowed profit increase.
	Section 3
Q21	The capital of the company Romanian Foreign Mixed
Q22	The number of employees of the company 1–9 employees 10–49 employees 50–249 employees over 250 employees
Q23	The region from the country Transilvania; Muntenia; Moldova; Dobrogea; Crisana; Banat; Oltenia; Maramures; Bucovina
Q24	Agreement for results publishing Yes No

* 5 full implemented; 1 not at all implemented. ** 5 total agree; 1 not at all agree.

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