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Directions of the Development of the 3D Printing Industry as Exemplified by the Polish Market

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Abstract
The Fourth Industrial Revolution, also known as Industry 4.0, is about connecting the physical world with the virtual world in real-time. With the advent of the Fourth Industrial Revolution, manufacturing companies are introducing a number of solutions that increase productivity and personalize finished products in line with the idea of Industry 4.0. The application of, among others, the following: 3D printing, the Internet of Things, Big Data, cyber-physical systems, computing clouds, robots (collaborating and mobile), Radio-frequency identification systems, and also quality control and reverse engineering systems, is becoming popular. There are still not enough studies and analyses connected with the Polish 3D printing market, and also attempt to determine the attitude of those studies and analyses to the implementation of the Industry 4.0 conception. In connection with what is stated above, the principal objective of this paper is to determine the directions of the 3D printing industry development. In this publication, it is as well the survey respondents' opinions relevant to opportunities and threats connected with the implementation of the Industry 4.0 conception in an enterprise are presented. The survey was conducted on a group of 100 enterprises and scientific research institutes in Poland, offering and/or applying additive technologies.

Keywords
additive manufacturing, 3D printing, Industry 4.0, production development, production engineering.

Introduction

In every enterprise, changes are treated as processes occurring in the normal course of events, the principal purpose of which is to increase competitive advantage. The changes in question may be relevant to both tangible resources (buildings, technical devices, machines, means of transport and warehouse supplies), and the intangible ones (organisational structure, employees' knowledge and competencies and organisational culture).

A factor that stimulates a company's constant self-improvement is customer expectations, which are constantly ever-higher; customers demand a product that is tailored, available as fast as possible and at the most economical price, whilst maintaining quality standards (Hamrol, 2020; Lysenko-Ryba and Zimon, 2021; Żywicki and Zawadzki, 2018). For that purpose, many conceptions have been developed, and the one of Industry 4.0 has been enjoying the greatest popularity in recent years.

Industry 4.0 is a comparatively new notion in the manufacturing sector, and the fourth stage of the industrial revolution, consisting of combining the real world with the virtual one in real-time (Schwab, 2016). This conception endeavours to create a smart factory, in which smart networks connect machines, processes and systems, and also products, customers and suppliers (Paszkiewicz et al., 2020; Łukasik and Stachowiak, 2020).

Analysing the sector of small and medium-sized enterprises (SME), it is possible to observe increased interest in, and the awareness of, the benefits of digitalisation. For instance, by the study of SIEMENS (2020), the number of implementations of the Industry 4.0 conception in Poland is rising constantly. In 2018, it was at the level of 4.5%, In turn, in 2020 its level reached 7.2% already. Another important piece of information acquired using research is that interest in the implementation of the Industry 4.0 concep-

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tion in companies increased twice (in 2018 – 11%, in 2020 – 25.5%). The research conducted on a group of surveyed manufacturing enterprises in the SME sector in 2020 indicated that implementations in companies within the scope of Industry 4.0 encompassed, in most cases, changes connected with manufacturing optimisation upon the basis of data analysis, or predictive maintenance. Among them, an important role was also played by 3D printing, the level of implementation of which is also increasing (in 2018 – 14.5%, in 2020 – 18.3%), which was principally caused by dynamic additive manufacturing development in recent years (SIEMENS, 2020).

The AM (Additive Manufacturing) methods are enjoying even more popular owing to their benefits in terms of manufacturing prototypes and prototype machine parts. That is principally connected with reducing manufacturing time, and also decreasing costs, particularly in the case of prototypes with complex geometry. In addition, particular attention ought to be paid to the possibility of manufacturing details in a geometry that has hitherto been impossible to obtain with the application of traditional manufacturing methods, and/or tailored geometries (Redwood et al., 2017; Siemiński and Budzik, 2015; Badiru, 2017). To streamline management and manufacturing finished products, work is conducted within the realm of additive manufacturing development on new technologies and printing materials, and also on integrating systems and processes with the application of, among others, the Internet of Things, Big Data, cyber-physical systems, computing clouds, robots (collaborating and mobile), RFID systems, and also quality control and reverse engineering systems (Horst et al., 2018; Shahrubudin et al., 2019; Turek et al., 2020; Guo et al., 2020; Li et al., 2020).

In connection with what is stated above, the principal objective of this paper is to determine the directions of the 3D printing industry development. In this publication, it is as well the survey respondents' opinions relevant to opportunities and threats connected with the implementation of the Industry 4.0 conception in an enterprise are presented. The survey was conducted on a group of 100 enterprises and scientific research institutes in Poland, offering and/or applying additive technologies.

3D printing industry development

Analysing numerous reports relevant to additive technologies, it is possible to conclude that more and more 3D printers are sold all over the world every year. The Wohlers Report 2018 states that, in 2015, the number of such devices sold all over the world amounted to 283,885, in 2016 to 424,185, whilst in 2017 to as many as 528,952. The countries in which the value of the implemented systems in question was highest in 2017 were: USA (35.9%), China (10.6%), Japan (9.3%), and also Germany (8.4%). The greatest player in the industrial 3D printers market in 2017 was Stratasys (27.2%), followed by 3D Systems (9.8%), and also EnvisionTEC (8.0%). Comparing The Wohlers Report 2018, and also the Wohlers Report 2015, it is also possible to observe that the 3D printer manufacturing market is divided between more and more companies every year and that there are ever more manufacturers of tchem (Wohlers, 2018, 2015).

Following the 3D HUBS Report, in 2019 the estimated average global value of the 3D printing market was at the level of 12.1 billion USD (or, between 9.9 billion USD and 15.0 billion USD in the opinion of various analysts), recording a 25% year-to-year increase since 2014. It is expected that average market growth for the next five years will be at the level of 24% Compound Annual Growth Rate, to reach 35.0 billion USD by 2024, and doubling every three years (approximately). Of course, this state of the matters will be exerted an influence upon both by changing external factors (customer requirements, national policies and the conditions of economy), and the internal ones (degree of adaptation to lot production, material and system development, or reducing total costs) (3D HUBS, 2020).

Analysing the Polish market, one notices strong growth dynamics as well. Domestic start-ups, among others, printer manufacturers: Zortrax, Omni3D, Kreator 3D or ZMorph, are the brands that are becoming more and more popular not only in Poland but in the international market as well.

A similar situation is observed in the case of so-called filaments (materials used for printing) manufacturers. Well-known brands include to mention, but a few, Fiberlogy, PRI-MAT3D and AEMCA.

An increase in the sale of 3D printing printers and filaments is noticeable in a popular online marketplace. For instance, Allegro (an online e-commerce platform) established a 3D printer category, and, following the PRINTELIZE Report, in 2013 the number of auctions, in particular, segments was as follows (PRINTELIZE, 2015);

- 3D printer parts – 30 auctions;
- filaments – 60 auctions;
- printers – 30 auctions.

In turn, analysing the current data for January 2021, it is found that there were (Allegro, 2021):

- 14,785 auctions (493-fold increase in comparison with 2013) – in the case of 3D printer parts;
- 15,694 auctions (262-fold increase in comparison with 2013) – in the case of filaments;
- 2,687 auctions (90-fold increase in comparison with 2013) – in the case of printers;
- 944 auctions (a new category) – in the case of resins.

The analysis is presented graphically in Fig. 1.

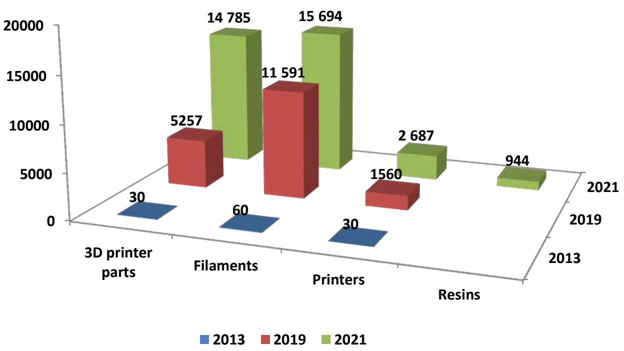

Fig. 1. The number of auctions in particular categories at *allegro.pl* [PRINTELIZE, 2015; Budzik et al., 2019; Allegro, 2021]

It is worth paying attention to the fact that the actual quantitative data relevant to the sold printers in 2013 were relatively low, therefore, it was comparatively easy to achieve high growth levels as well. Moreover, the 3D printer market is increasing due to the ever-greater popularity of desktop printers, which, due to their price, are attracting ever more users.

A survey on 3D printing development

The course of research process

The research was conducted at the turn of 2019and 2020 on a group of 100 enterprises and scientific research institutes conducting manufacturing activity on the territory of Poland. The survey was principally addressed to managerial personnel in the 3D printing industry enterprises.

As the tool of research, a survey questionnaire was made available by CAWI (Computer Assisted Web Interview) method, and also PAPI (Paper and Pencil Interview), was applied. It included three kinds of questions: closed, semi-open and open. The survey questionnaire included as well particulars, in which the survey respondents were requested to provide precise information relevant to the territorial scope of the activity, industries, company's size, and also market life. For data analysis, the STATISTICA 13 program was applied.

First and foremost, in the statistical analysis, contingency tables, in which both the quantitative and percentage distribution of particular answers were presented, were applied. Answers to the open questions relevant to the directions of activity development, and also opportunities and threats relevant to the implementation of the Industry 4.0 conception in an enterprise, were categorised and presented graphically in order of the most frequent answers. To determine correlations between qualitative traits, Pearson's chi-square test of independence was used. The research was conducted at the level of significance of $\alpha = 0.05$. The significance level informs about the probability of making a mistake during the conducted research. Usually, it is assumed at the level of 5%, which allows for a test error 5 times out of 100. Based on the collected data, p (test probability) was calculated, which allows for a rejection or indicates no grounds for rejecting the assumed null hypothesis. The lower the value of the test probability, the stronger the relationship or differences that have been checked. The following assumptions are adopted: $p < .05$ – a statistically significant correlation (marked *); $p < .01$ – a highly- significant correlation (**); $p < .001$ – an extremely statistically significant correlation (***).

Survey results

Upon the basis of the conducted research material, the analysis of the territorial scope of the activity was conducted. In Fig. 2, it is shown that 38% of the researched entities are enterprises active all over the country. In turn, 37% of the survey respondents declared that their activity was conducted in the international market. The global scale of activity was declared by every fifth of the survey respondents. Only 4% of enterprises are active within a single region, and 1% locally.

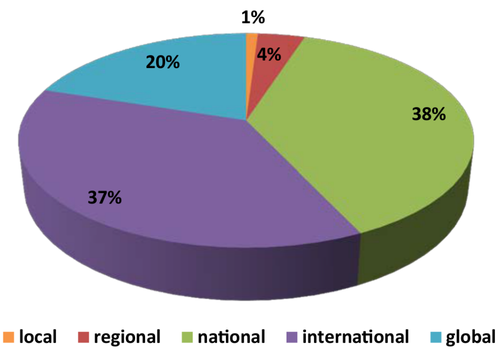

Fig. 2. The territorial scope of the activity

Another question in the survey was relevant to the enterprise's size. Analysing the data presented in Fig. 3 gives rise to the conclusion that nearly 1/3 of the survey respondents (32%) are employed in micro-enterprises (labour force smaller than 10 people, with the annual turnover not exceeding 2 million EUR). 32% of the survey respondents declare to be employed in small enterprises (labour force smaller than 50 people, with the annual turnover and total annual balance not exceeding 10 million EUR). Every fifth of the survey respondents is employed in medium-sized enterprises (labour force smaller than 250 people, with the annual turnover and total annual balance not exceeding 43 million EUR). In turn, 16% of the survey respondents are employed in large enterprises (employing no fewer than 250 people, with the annual turnover higher than 50 million EUR, and a total annual balance of 43 million EUR). At this point, it is worth paying attention to the fact that a substantial number of large enterprises results from differences in interpreting the question relevant to the enterprise's size. In the case of companies with foreign capital, having a branch in Poland, the survey respondents might have taken not the branch's size, but rather the entire enterprise's size one.

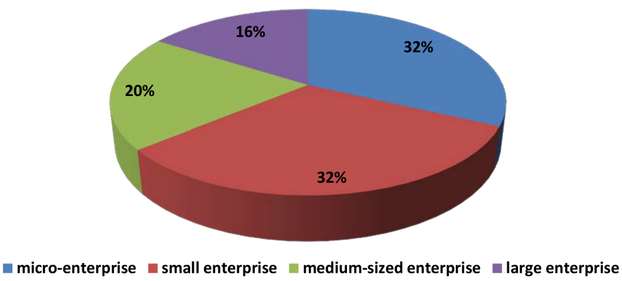

Fig. 3. Enterprise size

The structure of the survey respondents depending upon market life is presented in Fig. 4. It is indicated by the data presented therein that the study group is dominated by companies with a short history.

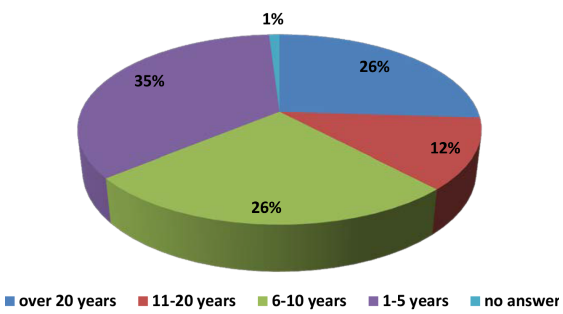

Fig. 4. Market life

More than 1/3 of the survey respondents (35%) declared that their company was established 1–5 years ago. Every fourth stated it has been active for 6–10 years, and 12% of the survey respondents stated that it was established 11–20 years before. Every fourth of the companies has been in the market for more than 20 years. 1% of the survey respondents did not answer this question.

Another question in the survey was relevant to the industry represented by a company. In this case, the survey respondents could choose a few answers, or formulate their own. As it can be concluded from Fig. 5, it is declared by the majority of the survey respondents that they are active in the following industries: automotive (58%), electromechanical (57%), and also 3D printing (52%), followed by the aviation (45%), education (41%), medicine (31%) and the space industry (21%). Other areas of the activity of enterprises presented in the survey questionnaire are chemical industry (3%), industrial design (2%), automatics and robotics (2%), agriculture (2%), and also, among others, the defence industry, railways, arts, furniture and houseware articles industry, with the result at the level of 1%.

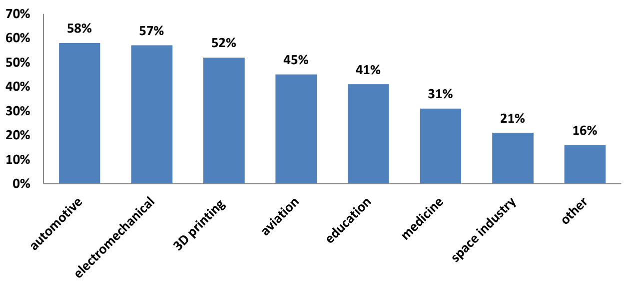

Fig. 5. Activity in particular industries

Processing research results

Of 100 of the survey respondents, 93 answered the question on the development of an enterprise in the nearest future. 75% of them stated the company wanted to develop, whilst 1% could not decide whether it was so. A negative answer was given by 24% of the survey respondents (Fig. 6).

In the further part of the research, the directions of enterprise developments in the case of companies applying additive technologies were verified. The answers are presented in Fig. 7. As it can be concluded from the analysis, the largest number of the enterprises planning to develop is going to purchase additional 3D printers. This direction of development was indicated in 61% of cases. Another aspect is purchasing scanners and modern print quality control measurement systems, mentioned by 16% of the survey

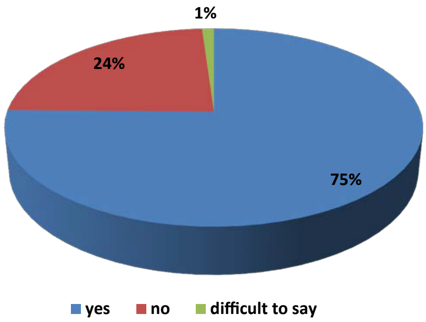

Fig. 6. Development of enterprise activity

respondents. 14% of the survey respondents declared to be willing to participate in training events, and 14% found it possible to improve their market position using R&D and also launching new products. Purchasing reverse engineering systems was mentioned by 11% of them. Other directions of enterprise development are: developing lines for processing polymers (6%), purchasing new printing material (3%), developing own printer (3%), and also modernising and streamlining printers (3%).

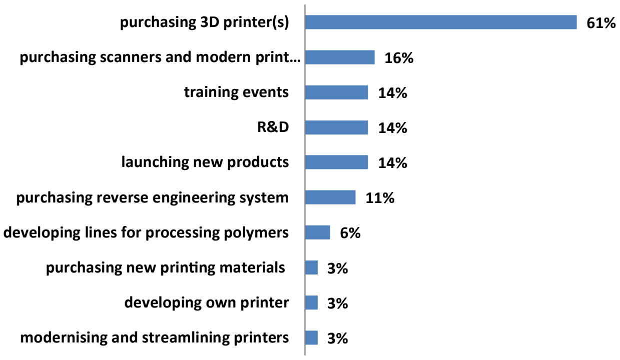

Fig. 7. Directions of enterprise development

The further part of this research consisted in verifying whether there is a correlation between willingness to develop and:

- company's size,
- the territorial scope of the activity,
- market life,
- industry.

The adopted level of significance was $\alpha = 0.05$. For analysis, Pearson's chi-square test of independence was used.

The following research hypotheses were formulated:

- H_0 – an enterprise's willingness to develop is not connected with its size/the territorial scope of the activity/market life and industry;
- H_1 – an enterprise's willingness to develop is connected with its size/the territorial scope of the activity/market life and industry.

In Table 1, the collation of the results of the conducted analysis is presented.

Table 1
Results of Pearson's chi-square test of independence. Selected parameters and an enterprise's willingness to develop

Parameter	p
Company's size	0.03656*
Territorial scope of the activity	0.23119
Market life	0.89064
Automotive industry	0.58588
Electromechanical industry	0.88380
3D printing industry	0.59259
Aviation industry	0.57999
Education	0.52549
Medicine	0.93550
Space industry	0.90101

As it can be concluded from the conducted research, an enterprise's willingness to develop $p < \alpha$ ($p = 0.03656^*$) is exerted an influence upon by a company's size. In the remaining cases, the correlation is not observed ($p > \alpha$).

The data in Fig. 8 show that an enterprise's willingness to develop is at the highest level among small enterprises. As many as 90% of the survey respondents declaring that they belong to this group indicated that they wanted to increase the scale of their activity. Of the large enterprises, 85% intend to implement development plans in the nearest future. In the case of the sector of micro-enterprises, 72% declare that they want to implement improvement activities. In turn, development plans exist only in 50% of the group of medium-sized enterprises.

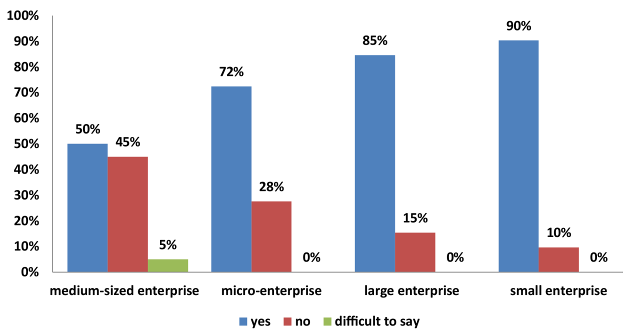

Fig. 8. Declaration of an enterprise's willingness to develop taking into account company's size

Analysis of opportunities and threats resulting from the implementation of the Industry 4.0 conception

In the last part of the survey questionnaire, in open questions, the survey respondents were asked to present their opinions relevant to opportunities and threats being part and parcel of the implementation of the Industry 4.0 conception in an enterprise. In the course of analysis of the results, the answers of the survey respondents were categorised and put into groups of similar answers, and next presented graphically, with the number of identical comments being stated.

In Fig. 9, the collation of collective results of the analysis relevant to opportunities arising in connection with the implementation of technologies typical of the fourth industrial revolution is presented. Answers were received from 28 of the survey respondents.

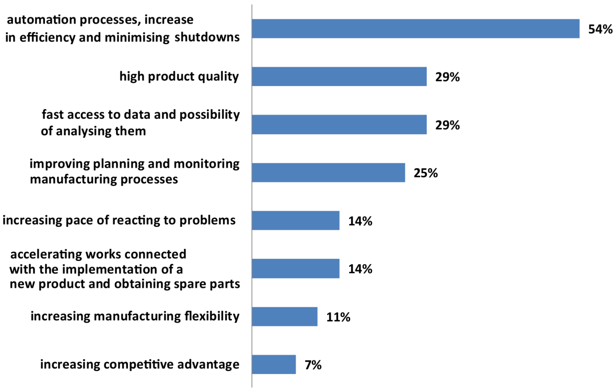

Fig. 9. Opportunities resulting from the implementation of the Industry 4.0 conception

Among the benefits, the survey respondents enumerated: automation processes, increase in efficiency and minimising shutdowns (54% of the survey respondents), high product quality (29%), fast access to data and possibility of analysing them (29%), improving planning and monitoring manufacturing processes (25%), increasing pace of reacting to problems (14%), accelerating works connected with the implementation of a new product and obtaining spare parts (14%), increasing manufacturing flexibility (11%) and increasing competitive advantage (7%).

As it can be concluded from the conducted research, in most cases the answer relevant to the opportunity of the implementation of Industry 4.0 in an enterprise is automation processes, which, in turn, contribute to an increase in productivity and minimising shutdowns. Albeit the automation of a manufacturing plant is connected with costly investments connected with the purchase of industrial robots, together with necessary infrastructure and control software, however, it renders it possible to use the possessed resources better and shorten manufacturing time. Therefore, it is advisable to weigh up the costs and possible profits to be fully aware of the consequences of changes and related effects. In addition, due to the automation of manufacturing processes, the risk of error is reduced to the minimum, which results in reducing the scale of manufacturing faulty parts. All these factors decrease costs, and also improve product quality, which offers enterprises enormous opportunities (Moeuf et. al., 2020; Ibarra, 2018).

Other benefits mentioned in the survey questionnaires include fast access to data, and also the possibility of analysing them easily. Applying the Internet of Things, computing clouds or Big Data facilitates access to information on manufacturing and also renders it possible to control the current functioning of machines. It is becoming easier as well to manage manufacturing in remote branches (Zhong et al., 2017; Kache and Seuring, 2017). This fact contributes to better planning and monitoring manufacturing processes, which was appreciated by the survey respondents as well.

One of the possible applications of the Internet of Things is collecting data relevant to equipment condition and the course of manufacturing processes. Comparing the archive readings of machine parameters with the current data, one can predict breakdowns likely to happen in the future, and also their causes and places where they will occur. The idea of predictive maintenance constitutes, therefore, an additional benefit owing to avoiding repair costs, and also shutdowns in manufacturing (Jamrozik, 2018).

The fourth industrial revolution provides as well an opportunity to shorten the time required to design and launch products in the market. Such opportunities are provided, among others, by applying 3D printing, which renders it possible to manufacture prototypes in a shorter time and test them in real-life conditions. This way, engineers can make changes in the design the moment they find it required until the demanded result is received. Moreover. applying additive technologies renders it possible to obtain spare parts comparatively easily, which is another important benefit for enterprises (Handal, 2017).

The survey respondents pointed out as well that, by the idea of Industry 4.0, manufacturing is tailored. The tasks of companies will be to develop a tailored product, at a competitive price and in a short time. Using automation, the manufacturer will avoid high costs connected with retooling machines, because all activities within this scope will be conducted without the participation of the human labour force (Schwab, 2016). Adjusting to market requirements is, therefore, a condition sine qua non to ensure the competitive advantage of an enterprise.

The question on the threats connected with the implementation of the Industry 4.0 conception was answered by 28 respondents. The results are presented graphically in Fig. 10.

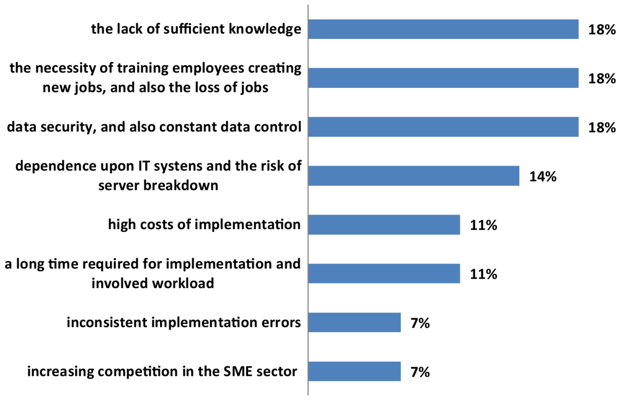

Fig. 10. Threats resulting from the implementation of the Industry 4.0 conception

Fears connected with the fourth industrial revolution in most cases were connected with: the lack of sufficient knowledge (according to 18% of the survey respondents), the necessity of training employees, creating new jobs, and also the loss of jobs (according to 18% of the survey respondents), data security, and also constant data control (according to 18% of the survey respondents), dependence upon IT systems and the risk of server breakdown (according to 14% of the survey respondents), high costs of implementation (according to 11% of the survey respondents), a long time required for implementation and involved workload (according to 11% of the survey respondents), inconsistent implementation, errors which are made (according to 7% of the survey respondents), and also increasing competition in the SME sector (according to 7% of the survey respondents).

The analysis of the collected material gives rise to the conclusion that the greatest threats, in the survey respondents' opinion, may include the lack of sufficient knowledge among managerial personnel and employees. It is feared by the survey respondents, therefore, that both managers and ordinary employees are not sufficiently competent to lead companies through the digital transformation process. These seem to be reasons for these doubts. According to the SIEMENS 2019 and 2020 Reports, the educational system may still not be adapted to the described requirements of an innovative industry. Despite increased awareness of the Industry 4.0 conception in Poland, there are still not enough institutions offering adequate training within its scope (SIEMENS, 2019, 2020).

The implementation of Industry 4.0 may bring about changes in the labour market. In the context of professional competencies of engineers, it is becoming required to possess interdisciplinary skills, combining, to mention, but a few: automatics, mechanics, robotics, programming, or IT. In addition, increased internalisation forces engineers to be familiar not only with a selected software environment but, as well, to be able to communicate in foreign languages without major problems (ASTOR, 2017). Therefore, it will become necessary not only to train current employees but, as well, to acquire new ones. Such a situation may cause job losses among those who will fail to adjust to changes, and those who will be reluctant to gain new skills (McKelvey and Saemundsson, 2021). Moreover, society begins to fear that mass-scale robotisation will result in the loss of jobs, particularly those based upon repetitive activities.

Other threats which were mentioned are those of cyberattacks, and also dependence upon IT systems, and the risk of a server breakdown. Making the whole factory connected to the Internet may incur serious consequences. Therefore, it is becoming a challenge to secure data appropriately, and also to minimise the risk of their loss, and also of access being gained by unauthorised individuals. Enterprises will be forced to invest in products safe in terms of architecture, and also to employ highly qualified employees in charge of data security level (Abomhara and Kien, 2015; Ali et al., 2016).

The issue of a long time required to implement the Industry 4.0 conception, and also substantial workload and expenditure involved, is also referred to in the answers. The Internet of Things, AI, or automation and robotisation are key aspects in the implementation of Industry 4.0. Investments in digital transformations are highly expensive, and force enterprises to change their business models, which requires time. Moreover, the transition from the level of Industry 3.0 to that of 4.0 is an extremely complex process, and a highly risky one, too, therefore, it has to be conducted consistently and be divided into stages (Herrmann, 2018; Deloitte, 2017). Errors in the course of implementation may have an enormous impact on a company, which was pointed out by the survey respondents as well.

The survey respondents also fear that the fourth industrial revolution will become a threat to the SME sector. Large corporations will be willing to implement modern technologies, whilst small and medium-sized enterprises may not be able to afford it (Sarı, 2020). Therefore, there is a risk of a fast loss of market share by companies that fail to adjust to the new situation.

Conclusions

In every sphere of manufacturing enterprise activity, it is justifiable to perfect a work station and also manufacturing processes, all the time. In the times of the fourth industrial revolution, it extremely important as well to implement solutions based on modern technologies and tools for manufacturing management, and also constantly raise the competencies of managerial personnel and employees.

However, it ought to bear in mind that not all organisations will be able to implement identical practices because there are no versatile technologies and tools which could be applied anywhere and without proper consideration. In every case, it is necessary to analyze own needs and possibilities, and also opportunities and threats related to the implementation of certain solutions.

Upon the basis of knowledge obtained owing to reviewing the literature, and also conducting and analysing surveys, it is possible to conclude that the 3D printing industry is undergoing constant development. Evermore modern and specialised 3D printers, and also better software and new materials for 3D printing, are developed. The hardware is becoming ever more economical and popular, increased interest is visible both in the industry and among customers who are natural persons.

In Poland, the majority of the 3D printing industry enterprises intends to develop their activity, and improve their market position, first and foremost, using purchasing new 3D printers. There is, as well, more and more awareness of the Industry 4.0 conception. Among the benefits connected with the implementation of it, the survey respondents enumerated, first and foremost, automation processes, increase in efficiency and minimising shutdowns, ensuring high product quality, and also fast access to data and possibility of analysing them. In turn, principal fears connected with the arrival of the fourth industrial revolution were relevant to the lack of sufficient knowledge among managerial personnel and employees, which, as a result, will render it necessary not only to organise training but, as well, to acquire new specialists. In the times of digitalisation, it is found extremely important as well to ensure data security, and also controlling it all the time.

The authors hope that the presented research result will turn out to be useful for companies and scientific research institutes connected with the 3D industry printing, and also will exert a positive influence upon decisions relevant to further development.

References

3D HUBS (2020). *3D printing trends 2020. Industry highlights and market trends*, 3D Hubs Manufacturing LLC.

Abomhara, M. and Kien, G.M. (2015). *Cyber security and the internet of things: vulnerabilities, threats, intruders and attacks*, Journal of Cyber Security and Mobility, 4, 1, 65–88, doi: 10.13052/jcsm2245-1439.414.

Ali, I., Sabir, S., and Ullah, Z. (2016). *Internet of things security, device authentication and access control: a review*, International Journal of Computer Science and Information Security, 14, 8, 456.

ASTOR WHITEPAPER: Engineer 4.0 (Not) ready for changes? (2017). from https://www.astor.com.pl/downloads/pliki/ASTOR_Whitepaper_Engineer40_Not_ready_for_changes_2019.pdf (accessed 10.02.2021).

Badiru, A.B., Valencia, V.V. and Liu, D. (2017). *Additive Manufacturing Handbook: Product Development for the Defense Industry*, CRC Press, USA.

Budzik, G., Przeszłowski, Ł., and Woźniak, J. (2019). *Study of the production capacity in the rapid prototyping industry* [in Polish: Badanie zdolności produkcyjnej w branży szybkiego prototypowania], Przegląd Mechaniczny, 2, 20–22, doi: 10.15199/ 148.2019.2.1.

Deloitte, *The fourth industrial revolution is here – are you ready?*, 2017, https://www2.deloitte.com/cn/en/pages/consumer-industrial-products/articles/industry-4-0-technology-manufacturing-revolution.html from (accessed 09.02.2021).

Guo, B., Ji, X., Chen, X., Li, G., Lu, Y., and Bai, J. (2020). *A highly stretchable and intrinsically self-healing strain sensor produced by 3D printing*, Virtual and Physical Prototyping, 15, 520–531, doi: 10.1080/17452759.2020.1823570.

Hamrol, A. (2020). *Quality engineering challenges on the way to sustainability*, Management and Production Engineering Review, 11, 4, 113–120, doi: 10.24425/mper.2020.136125.

Handal, R. (2017). *An implementation framework for additive manufacturing in supply chains*, Journal of Operations and Supply Chain Management, 10, 2, 18–31, doi: 10.12660/joscmv10n2p18-31.

Herrmann, F. (2018). *The Smart Factory and Its Risks*, Systems, 4, 6, 38, doi: 10.3390/systems6040038.

Horst, D.J., Duvoisin, CH.A., and Vieira, R. de A. (2018). *Additive Manufacturing at Industry 4.0: a Review*, International Journal of Engineering and Technical Research, 8, 8, 3–8.

Ibarra, D., Ganzarain, J., and Igartua, J.I. (2018). *Business model innovation through Industry 4.0: a review*, Procedia Manufacturing, 22, 4–10, doi: 10.1016/j.promfg.2018.03.002.

Jamrozik, W. (2018). *BIG DATA in the prediction service*, [in Polish: *BIG DATA w służbie predykcji*], Utrzymanie Ruchu, 4, 36–39.

Kache, F., Seuring, S. (2017). *Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management*, International Journal of Operations & Production Management, 37, 1, 10–36, doi: 10.1108/IJOPM-02-2015-0078.

Li, Z., Chen, Z., Liu, J., Fu, Y., Liu, Ch., Wang, P., Jiang, M. and Lao, CH. (2020). *Additive manufacturing of lightweight and high-strength polymer-derived SiOC ceramics*, Virtual and Physical Prototyping, 15, 2, 163–177, doi: 10.1080/17452759.2019.1710919.

Łukasik, K. and Stachowiak, T. (2020). *Intelligent management in the age of Industry 4.0 – An example of a polymer processing company*, Management and Production Engineering Review, 11, 2, 38–49, doi: 10.24425/mper.2020.133727.

Lysenko-Ryba K. and Zimon D. (2021). *Customer Behavioral Reactions to Negative Experiences during the Product Return*, Sustainability, 13, 2, 448, doi: 10.3390/su13020448.

McKelvey, M. and Saemundsson, R.J. (2021). *The grey zones of technological innovation: negative unintended consequences as a counterbalance to novelty*, Industry and Innovation, 28, 1, 79–101, doi: 10.1080/13662716.2020.1783216.

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia E., and Eburdy R. (2020). *Identification of Critical Success Factors, Risks and Opportunities of Industry 4.0 in SMEs*, International Journal of Production Research, 58, 5, 1384–1400, doi: 10.1080/00207543.2019.1636323.

Paszkiewicz, A., Bolanowski, M., Budzik, G., Przeszłowski, Ł., and Oleksy, M. (2020). *Process of Creating an Integrated Design and Manufacturing Environment as Part of the Structure of Industry 4.0*, Processes, 8, 9, 1019, doi: 10.3390/pr8091019.

PRINTELIZE (2015). *Research on the 3D printing market in Poland* [in Polish: *Badanie rynku druku 3D w Polsce*], https://printelize.com/pl/T/BadanieRynkuDruku3DwPolsce3 (accessed 09.02. 2021).

Redwood B., Schöffer F., Garret B. (2017). *The 3D Printing Handbook: Technologies, design and applications*, 3D Hubs, Amsterdam, The Netherlands.

Sarı, T., Güleş, H.K., and Yiğitol, B. (2020). *Awareness and readiness of Industry 4.0: The case of Turkish manufacturing industry*, Advances in Production Engineering & Management, 15, 1, 57–68, doi: 10.13052/jcsm2245-1439.414.

Schwab, K. (2016). *The Fourth Industrial Revolution*, Random House Lcc Us, USA.

Shahrubudin, N., Lee, T.C., and Ramlan, R. (2019). *An Overview on 3D Printing Technology: Technological, Materials, and Applications*, Procedia Manufacturing, 35, 1286–1296, doi: 10.1016/j.promfg.2019.06.089.

SIEMENS (2019). *Smart Industry Poland Report* [in Polish: *Raport Smart Industry Polska*], Polska.

SIEMENS (2020). *Smart Industry Poland Report* [in Polish: *Raport Smart Industry Polska*], Warszawa, Polska (accessed 09.02.2021).

Siemiński, P. and Budzik, G. (2015). *Additive techniques. 3D printing. 3D printers* [in Polish]: *Techniki przyrostowe. Druk 3D. Drukarki 3D*], Oficyna Wydawnicza PW, Warszawa, Polska.

Turek, P., Budzik, G., Oleksy, M., and Bulanda, K. (2020). *Polymer materials used in medicine processed by additive techniques*, Polimery, 65, 7–8, 510–515, doi: 10.14314/ polimery.2020.7.2.

Wohlers Report (2015). *3D Printing and Additive Manufacturing State of the Industry, Annual Worldwide Progress Report*. Wohlers Associates, USA.

Wohlers Report (2018). *3D Printing and Additive Manufacturing State of the Industry, Annual Worldwide Progress Report*, Wohlers Associates, USA.

www.allegro.pl (accessed 02.01.2021).

Zhong, R.Y., Xu, X., Klotz, E., and Newman, S.T. (2017). *Intelligent manufacturing in the context of industry 4.0: a review*, Engineering, 5, 3, 616–630, doi: 10.1016/J.ENG.2017.05.015.

Żywicki, K. and Zawadzki, P. (2018). *Fulfilling individual requirements of customers in smart factory model*, In: Advances in Manufacturing, LNME (185–194). Springer.