Industrial Engineering and Management of European Higher Education

Industrial Engineering and Management:
an Analysis of the European Educational offer in Academia and Companies in the Framework of Industry 4.0

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Introduction

Contemporary Industrial Engineering and Management deals with challenges of business, science and technology. The dynamic development of technology and organization of production commonly referred to as the "fourth industrial revolution" or Industry 4.0 (I4.0) is perceived as the answer to the challenges and opportunity to benefit from phenomena currently observed, such as internationalization, development of information technologies as well as hyper-competition. The term Industry 4.0 was first used in 2011 in Hanover Fair and referred to the German project "Das Zukunftsprojekt Industrie 4.0" which concern the subject of technological strategies combine with digitalization of manufacturing processes (Cao et al., 2015). The project strove to define a strategy for increasing competitiveness of German manufacturing enterprises by using modern technological solutions, including cyber-physical systems, the Internet of Things, cloud computing (Kagermann et al, 2013). In October 2012, the Working Group on Industry 4.0 presented a set of Industry 4.0 implementation recommendations to the German federal government. The recommendations focused on automation and data exchange in manufacturing technologies and processes which include Cyber-Physical Systems (CPS), the Internet of Things (IoT), Industrial Internet of Things (IIOT), cloud computing, cognitive computing and artificial intelligence.

Hence, Industry 4.0 is a complex approach in which the main goal is to create a smart factory, where systems of industrial automation are connected with highly advanced IT technology and new methods of work. The basis for the solution is the data transmitted by production systems in real time or close to it and communication mechanisms which show a huge potential to further development of company resource planning system. The existing potential of manufacturing systems is exploited by transforming separate automated manufacturing plants into fully automated and optimized production environment, the so called cyber-physical systems, which are the base of the smart factories, where data is flowing using the Internet communication protocols realizing data flows between human beings and machines (human to human, human to machine, machine to machine). Thanks to developed communication protocols, smart factories are able to react in real time on the potential mistakes and adapt to changing requirements of customers and the market. As a result, intelligent factories are producing competitive products (Sobieraj, 2018).

The five major features of Industry 4.0 are digitization, optimization, and customization of production; automation and adaptation; human machine interaction (HMI); value-added services and businesses, and automatic data exchange and communication (Posada et al. 2015; Roblek et al., 2016; Lu, 2017).

The solution has a huge potential and is dynamically developing. Nevertheless, despite the great interest in the concept of Industry 4.0 worldwide, there is no formally respected definition for it. It is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes" (Industrial Internet Consortium), or "a new level of value chain organization and management across the lifecycle of products" (Kagermann, Helbig, 2013) or "a collective term for technologies and concepts of value chain organization" (Hermann et al., 2015). Thus, Industry 4.0 is a heterogeneous concept, combining a number of solutions of a different nature, as presented in the Figure 1, and listed below (Rüßmann et al. 2015):

- IoT – Internet of Things,
- Simulation,
- Autonomous robots,
- Big Data and analytics,
- Cyber Security,

- Additive Manufacturing,
- Cloud computing
- Augmented Reality,
- Vertical and Horizontal Integration.

Some of these solutions focus on manufacturing process (i.e. Additive Manufacturing, Autonomous robots, Augmented Reality), the others on data processing (i.e. Cloud Computing, Cyber Security, Big Data and Analytics), communication schemes (i.e. Internet of Things), and organization (Vertical and Horizontal Integration, Simulation). Altogether they create business models benefiting from contemporary, world-class technologies implemented in all the areas of company's functioning.

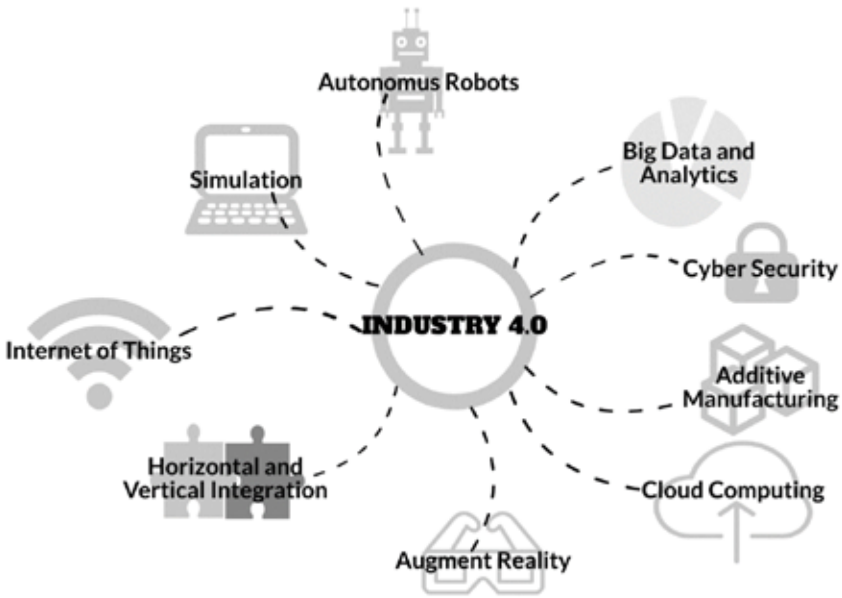


Figure 1 - Nine pillars of Industry 4.0

Considering solutions/pillars focused on **manufacturing processes**, they support the increase in efficiency of processes, their flexibility and safety.

Additive manufacturing, can be called 3d printing, which is the process of producing 3-dimensional physical objects on the base of the requirements of customer and designing it in CAD (Computer-Aided-design). The most popular way of using the additive manufacturing is for creating prototype, conceptual products, finished products or their components. It allows for production of small batches of the product to have less stock and to avoid overproduction. This technology allows for the Just-In-Time production system. It enables for the speed, versatility and flexibility of systems (Sobieraj, 2018). The technology is not new, it was first mentioned in 70s of XX century, but gained its popularity with development of tools enabling its implementation at industrial scale.

Autonomous robots are the machines which are programmed by a computer and perform automatically tasks in the manufacturing industry. They perform behaviors or tasks with a high degree of autonomy (without external influence). They execute complex activities which are hard and/or dangerous to perform by the human beings. In industrial environment robots can be used in various fields such as logistics, production, distribution. During performing the activities robots can be controlled by humans remotely. The machine and the worker can collaborate due to the human robot cooperation. The robot can perform tasks, but it can also learn from people some activities and even check the performance of workers. The technology was conceptualized in 70s of XX century and it is still developing; robots are becoming more and more user-friendly, their implementation potential increases (Keijzer, Klingebiel , 2020). Autonomous robots can be also used, with some help of cloud system, for tasks optimization and documentation (Lee, 2017).

Augmented Reality is a system which connect the real world with the one which is generated by computer. AR technologies contribute to increase in efficiency and effectiveness by raising qualifications and productivity of employees despite prior training. AR can be also be used in different type of trainings, e.g. fire prevention, while employees can move to a virtual situation using goggles, where a fire broke out and learn how to behave in such a situation. AR can potentially result in cost profile improvement, safety and health upgrading, better workplaces organization, which means also better performance of the work (Sobieraj, 2018). AR supports processes and work organization improvement as well. In workplace the devices that are used are interactive digital whiteboards, touch screen tables, distributed control rooms and other tools, which helps in brainstorming and visualization of the ideas of employees in company. With assistance of those devices the business benefits from decreased implementation time and reduced risk of introducing changes and innovative solutions to processes. Augmented Reality can be useful in maintenance area, facilitating identification of technical problem in machines, even those which are complex and difficult to maintain.

The pillars connected with **data processing** are technologies and solutions that enable dealing with large data sets, processing distributed data and extracting knowledge.

The concept of **Big Data** is commonly connected with the so-called 3xV, which represents volume, velocity and variety. Contemporary companies, implementing complex manufacturing processes and operating in global supply chain have to deal with:

- Data volume – the amount of data collected is significant, data can be collected from many sources, including sensors, SCADA (Supervisory Control and Acquisition DAta) systems, and others;
- Data velocity – business processes, including production and distribution need to be dynamic, which means that they generate a lot of data in short time, also their service must to pursue right away, because systems need the newest information about the operations to guarantee the appropriate reaction of the company's processes;
- Data variety – since data can be collected from various sources, they can be in different format, which results in the need of defining appropriate process of registration, storage or conversion.

Thanks to continuous information flow from devices, sensors and/or systems, the employees can make right decision and solve problems faster than they did before, with means of monitoring, managing and measuring (Sobieraj, 2018).

The whole concept of Big Data and Analytics is to process and analyse the large amount of collected data from all the fields of corporate activity, namely: algorithms, trends, information about customers, what preferences they have etc. In these times the data is extremely important for companies, disregarding their size and industry. The analysis of large data structures left on the Internet by customers allows to develop better products and offers that meet the needs of a specific target group. This pillar can help to predict various faults and prevent errors probability (Lu, 2020). It can also create algorithm which can reduce damages before they even happen (Hermann, M. et al , 2016). Company can greatly benefit from Big Data and Analytics use.

Cloud Computing, another technology considered as the pillar of Industry 4.0, is a model which allows ubiquitous, fast and easy access to all resources, which can be accessed quickly, with a small amount of effort and with minimum interaction with the supplier. This technology gives admission to the data at any time and without the necessity of building own infrastructure (Frazier, 2014). It allows to store and process the data in systems with possibility to view it provided for various users. Cloud Computing improves the operational efficiency of business enterprises, the emergence of new business models and the innovation of products and services. There are 3 types of the cloud computing model, such as SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). The first model gives access for the customer, but it depends on what he/she purchased. Next one depends on the access to customer applications on cloud, like software developers (Hedelind, Jackson, 2011). The use of the cloud by the enterprise makes it easier for the company to provide products and services, and clients have immediate access to them virtually from almost any place in the world (Sobieraj, 2018).

Cyber Security is extremely important pillar of Industry 4.0. Nowadays, many aspects of business are digitalized, important data is stored in clouds, which may be a threat to company – vital data can be stolen or blocked, software can be damaged by malicious attacks. Cyber security solutions are created to prevent those situations. Hence, it is important to build and implement the defence system and to train employees how to prevent and deal with cyber attacks (Hermann et al., 2016). The data is vital for every company and it needs to be protected.

Another pillar supporting development of companies deals with **communication** process. Communication is crucial for efficient and effective management. Since the role of machines (previously mentioned in Autonomous robots section) is continuously growing, communication with machines and between machines also needs to provided.

Hence, one of the key technologies of the fourth industrial revolution is **Internet of Things (IoT)**, which combines technical processes and their resources with business processes as well as with information, communication, control and management systems. It can use the Radio-Frequency Identification (RFID) which not only gives individual code for the products and machines but also allows to record the condition and share all the information between devices. In that way the devices can decide about the operations. This key technology is a global, dynamic network of physical devices, systems, platforms and applications that are able to establish communication with each other and share information obtained from the sensors, controls and intelligent commercial or industrial devices transmitting data over the internet (Cho, Woo, 2017). Internet of Things is inseparably connected with clouding, which enables the processing of transmitted data due to generating signals to facilitate the operation of machines (Sobieraj, 2018). It aims to benefit the factory with more effective system and working more efficiently (He, 2017).

Technical solutions for material processing and data flows are the very important aspects from Industry 4.0 perspective. Nevertheless, without proper approach to management, their potential cannot be fully exploited. The pillars referring to **management** create the framework for implementation of technical solutions and provide their efficient use.

Horizontal and vertical integration are two approaches of systems integration of Industry 4.0 (Alcácer, Cruz-Machado, 2019). **Vertical integration** is a strategy which pertains to level of integration of factory and systems that are flexible and reconfigurable inside the factory (Wang, 2016). It aims to connect all of the logical layers of the organization for instance marketing, sales, field layer IT and many more. Collected data flows through all the layers willingly and self-evidently, which allows to make the decision on the base of the data. The company driven by this strategy is able to efficiently react on the changes of the market signals and new opportunities which means that it leaves the business with competitive advantage. Vertical integration ''digitizes" all the process within entire organization, considering all data from the manufacturing processes, e.g., quality management, process efficiency or operations planning that are available on real-time. (Alcácer, Cruz-Machado, 2019) .

On the other hand, **horizontal integration** is focused on taking over companies to create comprehensive value chain. This strategy project connection of the network of CPs and enterprise systems, which brings levels of operational efficiency, automation and flexibility into production operations. According to several authors (Salkin et al., 2018; Foidl, Felderer, 2016; Posada et al., 2015; Stock, Seliger, 2016; Wang et al. 2016) **the paradigm** of I4.0 in manufacturing systems has another dimension between horizontal and vertical integration considering the entire product lifecycle. This kind of integration is based on vertical and horizontal integrations (Foidl, Felderer, 2016).

Simulation supports implementation of contemporary solutions, it can also be used to analyse performance and support product and processes design. It is the digital tool which can be used to conduct the measurement of the selected characteristics and behaviours. The benefit from simulation is cost and risk mitigation – decision options and project variants can be developed and analysed without disturbing system operation and using physical resources. Simulation provides opportunity to bring the most effective results in shop-floor management and correction to system in planning operation (Hofmann, Rüsch, 2017). The new simulation modeling paradigm is based on the concept of Digital Twin (DT). An ultra-high-fidelity simulation is provided by the DT concept and it plays an important role in I4.0. (Rodicˇ,2017).
All the pillars of Industry 4.0 are the solutions developed for companies. The company that decides to follow Industry 4.0 strategy implements them – they are not obligatory, however, they constitute innovation and development friendly environment.

The company that benefits from cyber solutions and strives for Industry 4.0 level is the system that includes not only social and technical elements (as defined for traditional company), but also cyber ones. Therefore it is referred to as **Cyber-Physical System** (CPS). CPS is expected to provide favourable solutions to already existing industrial systems to change the operation and their role (Bagheri et al., 2015). Cyber Physical System are industrial automation systems which cooperate with networking, physical objects and computing (Bagheri et al., 2015; Shafiq et al., 2015). CPS collaborate with computing units that are closely related to the surrounding physical world and its current processes, while providing and using the services available on the internet. Cyber-Physical System and Internet of Things are communicating and collaborating in real time with each other and with human beings. The internal services and cross organizational are provided used by contributors of the value chain. Cyber Physical System contains of sensors and actuators. The data exchange takes place through embedded computer terminals, cloud, wireless applications and other devices. CP system can cooperate in planning, designing, analysis and can do much more, but it needs to be properly integrated, dynamic and complex (Lasi et al., 2014). In Cyber Physical System, there are two factors which are crucial in enhancing the industrial performance: autonomy and decentralization (Ivanov et al., 2016).

CPS are able to increase productivity, support growth, modify workforce efficiency and produce higher quality goods at lower costs due to collection and analyse data. With the approach of wireless communication, CPS has a lot to offer and has a big impact on Information and Communication Technologies as well as on system technology in the company, especially with the help of smartphones and sensor technologies (Webster, Watson, 2002). In manufacturing area, Cyber Physical Production System (CPPS) is expected to create a new generation of industry and dominate manufacturing system. It could be achieved by integration with Cyber Physical System (Monostori et al., 2016). Both of those system will be activated and forced by the development of ICT, data related procedures as well as automation and production technologies. The CPPS integrates networking, physical objects and computing just as CPS. It involves human beings, machines and products. Combination of all those factors provides the production of highly qualified products with lower costs and with time efficiency (Lasi et al., 2014). The CPPS and embedded computer networks are responsive for controlling and monitor the processes as well as for performance evaluations and feedback loops. Virtual Engineering Objects is also one of the specialized form of CPS; it is mining data and transferring it for storing, improving, using and sharing experience and knowledge related to engineering artefacts (Stock, Seliger, 2016). It supports decision making in industrial design and production especially in factory planning due to execution of knowledge management (Posada et al., 2015). Another form of CPS is Virtual Engineering Process (VEP), which presents the knowledge in the field of production processes with all available data which are required about manufacturing. The third specialized form of CPS is Virtual Engineering Factory which is derivative from experience knowledge of engineering factory (Stock, Seliger, 2016).

Hence, considering the approach presented, the relations between contemporary solutions, companies and Industry 4.0 approach can be presented as in the Figure 2. Industry 4.0 is the general idea embracing numerous solutions, including the pillars listed, and Cyber-Physical System is the enterprise benefiting from solutions within pillars and striving for Industry 4.0 level.

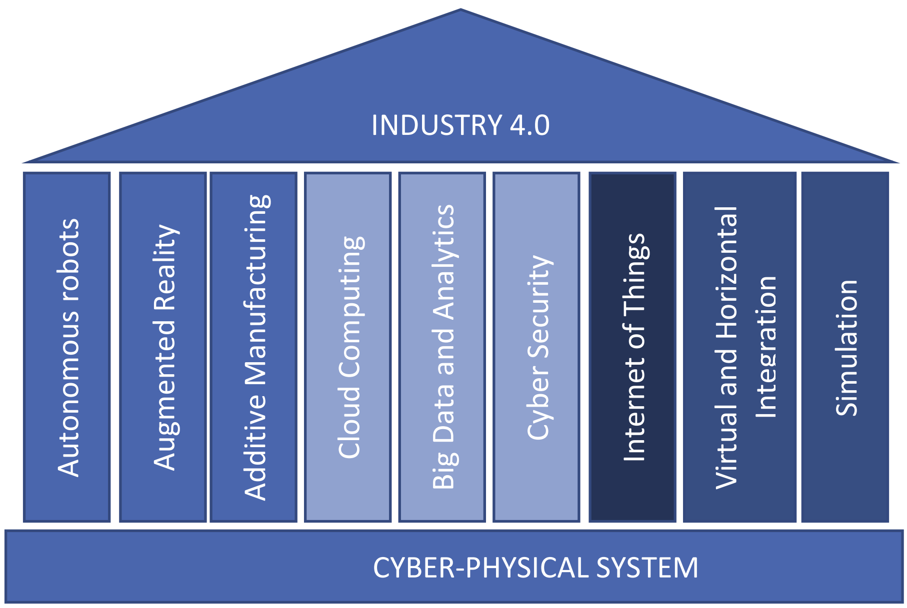


Figure 2 - Relations between CPS and I4.0

The knowledge on Industry 4.0 is complex and multidisciplinary, and it requires some stimulations: developing new content as well as methodologies and methods, and providing instruction by skilled experts. The stimulator role is played by educational system – since the solutions within Industry 4.0 are advanced and complex, it is generally Higher Education Institutions which conduct research and teach potential users and developers of I4.0.

Research background

To discuss convergencies and divergencies between scientic/academic knowledge and knowledge offered by HEIs to students, research methodology was designed and implemented.

The first stage of the research is to characterized its background by identification of knowledge resources within Industry 4.0 field, disciplines it is located in, keywords and trends recognized.

The methodology defined for research background identification was based on literature review on Web of Science and Scopus databases. Limiting the databases is in line with recommendations regarding the number of databases used (Green et al., 2006). Research procedure was divided into three stages, namely, according to guidelines (Strozzi et al., 2017, 2-3):

1. identifying the scope of the analysis,
2. identifying and locating keywords, type of documents, language, databases,
3. selection, assessment and synthesis of the existing set of completed, reviewed and registered in the analysed data basis scientific papers, developed by researchers, scientists and practitioners.

Stage 1: The scope of the analysis was limited to the indexed bases, namely Web of Science Core Collection and Scopus. These bases are broadly recognized over the world, used by academics and professionals for research and presented in bibliometric analyzes for scientific level assessment of individuals and HEIs.

Stage 2: The documents selected for analysis were the full-text scientific papers written in English and available in WoS and/or Scopus. Basic term sought for was Industry 4.0, in further stages the so called 9 pillars of Industry 4.0 were used as well for deepened analysis.

Stage 3: The implemented method of bibliometric analysis was the Systematic Literature Network Analysis (SLNA) method introduced by Colicchia and Strozzi (2012). The publications available were analyzed in terms of growth of knowledge (number of publications over the years), disciplines they were assigned to, geographical location of the author/HEI and finally the content.

Since the term "Industrie 4.0" originated in 2011 from a German government project in the high-tech strategy, and it was first publicly introduced in the same year at the Hannover Fair, scientific publications from 2011–2020 were searched with the term "Industry 4.0" in the over ten thousand references (Figure 3).

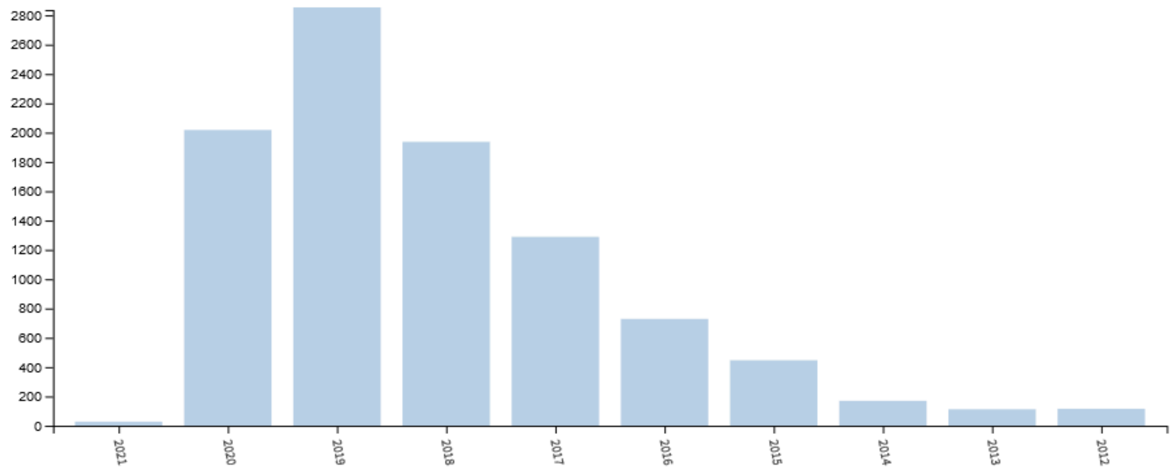


Figure 3 - Number of publications on Industry 4.0 topic

In the period considered (2011-2020) the total number of publications is over 10,000.
As the knowledge on Industry 4.0 grows, it affects many disciplines and areas of scientific interest. At this point, it can be stated that Industry 4.0 is a broad term, concerning numerous solutions, hence the research on Industry 4.0 is conducted in many industries and disciplines, as proven in the Figure 4.

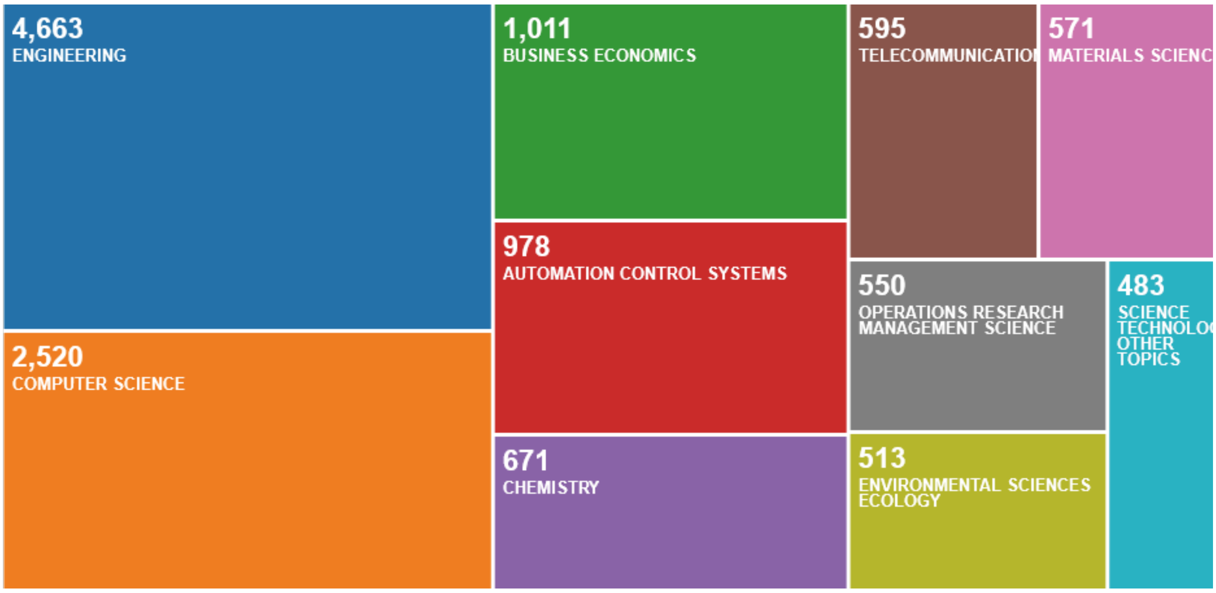


Figure 4 - Research fields for Industry 4.0

The total number of publications presented in the chart is not equal to the total number of publications identified, as only the disciplines with the most papers assigned to are depicted in the figure. Moreover, some papers can be assigned to more than one discipline. The most important conclusion is that the publications on Industry 4.0 are the most often associated with Engineering, while Business Science and Business Economics are less often referred to, nevertheless these aspects are also important. The composition is fully coherent with the scope of the IE3 projects as it refers to engineering and management in the same time.

Figure 5 depicts sources of publications, as presented the most contributing source is CIRP Proceedings.

Figure 5 - Sources of publications on Industry 4.0

Analysis of the sources leads to the conclusion that Industry 4.0 topic is strongly correlated with automation and manufacturing, as well as with production engineering and ICT (informaton and communication technology). Like in the previous figure the total number of publications presented and linked to journals in the chart is not equal to the total number of publications identified, as only the journals with the most papers assigned to are depicted in the figure.

For the surveyed population scientific publications, statistics show that researchers from the Germany and Peoples Republica of Chine dominate in the analyzed set of scientific papers, it is justified by the origin of the concept (Figure 6).

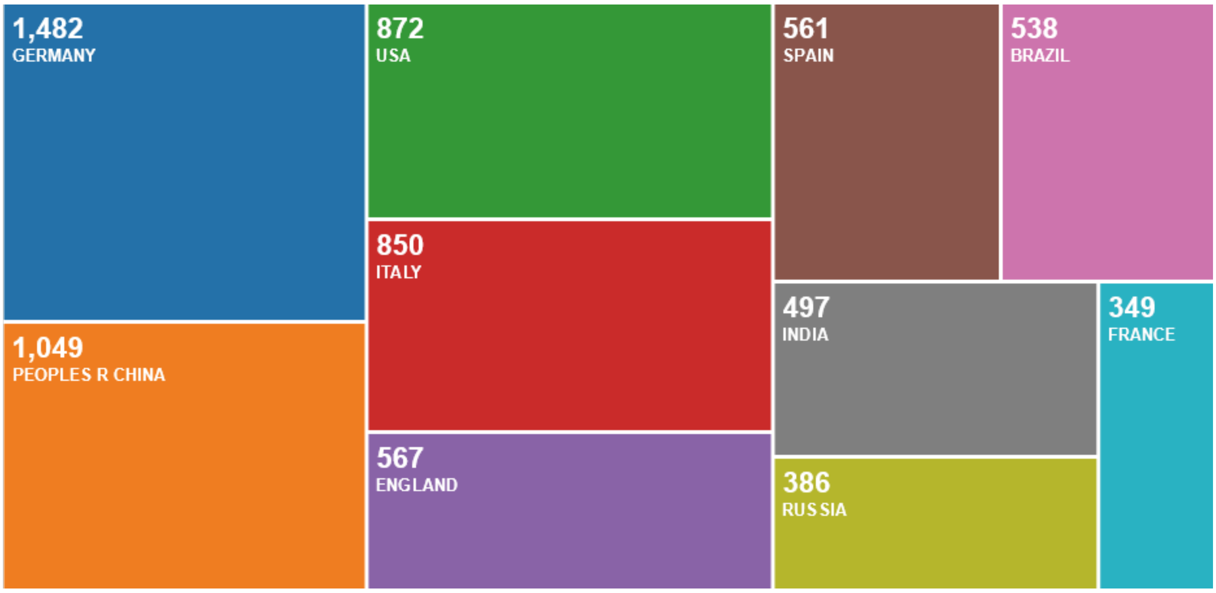


Figure 6 - Most contributing Countries/Authors affiliation for publications on Industry 4.0

Like in the previous figure, the total number of publications presented and linked to countries of affiliation in the chart is not equal to the total number of publications identified, as only the countries with the most papers assigned to are depicted in the figure.

The next step in the research procedure was to identify key trends and areas in Industry 4.0 field. Crucial related keywords were identified and listed in Table 2.

Table 2 - Publications on Industry 4.0 pillars

Key trends and areas in Industry 4.0 field	first published	nr of publications (mid 2020)
Big Data and Analytics	1974	46719
Cloud Computing	2007	40038
Internet of Things	2002	38139
Additive Manufacturing	1996	16109
Augmented Reality	1993	15664
Cyber-Physical System	2006	7045
Horizontal and Vertical Integration	1927	4970
Cyber Security	1999	4931
Autonomous Robots	1985	2828

The results of the first stage of the research constitute research background (presented in Figure 7).

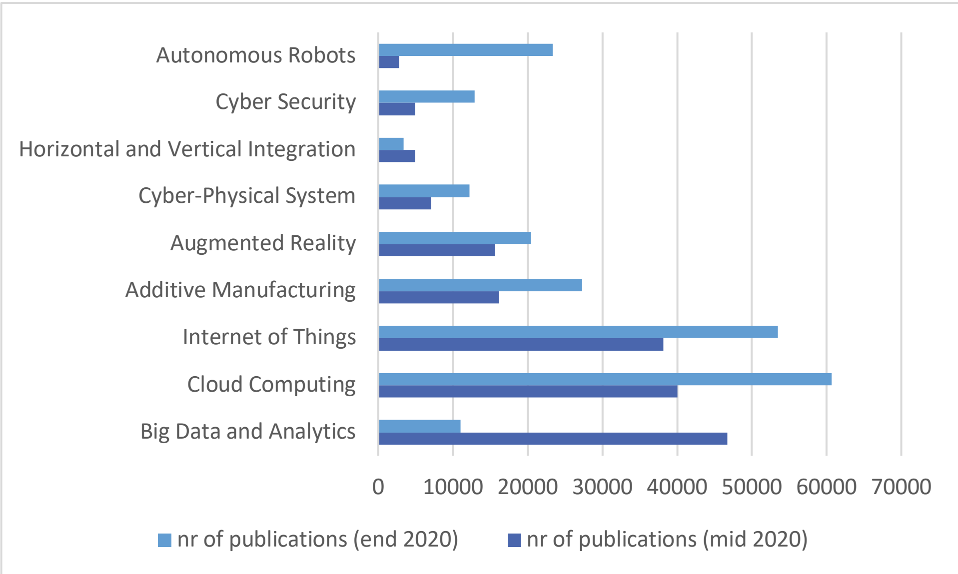


Figure 7 - Publications on identified keywords and their increase within six months

Growth of number of publications in each area can be observed. Again, as more than one keyword can be used in the paper the results cannot be simply added.

A mapping of Industry 4.0 based on bibliometric analysis has been carried out by (Janik and Ryszko, 2020). The map of the most frequent keywords in the field is in figure 8. The confrontation of the trends identified by authors of the present report and the ones identified in the map was conducted to analyze the literature from different perspectives and with various tools. Janik and Ryszko in their research used the following key words in their query: "Industr* 4.0", "smart industry", "smart industries", "intelligent industry", "intelligent industries", "smart factor*", "intelligent factor*","smart production", "intelligent production", "fourth industrial revolution" (the timeframe period covered years 1990-2018), "smart manufacturing", "intelligent manufacturing", "ubiquitous manufacturing" (the timeframe period covered only years 2012-2018).

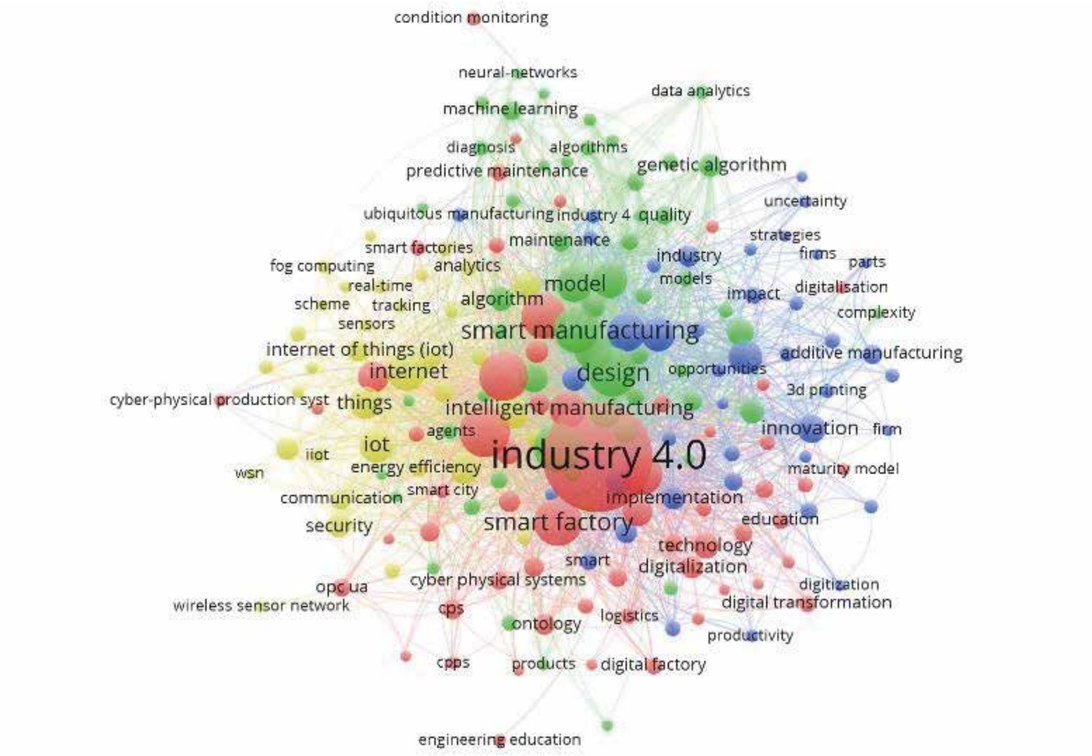


Figure 8 - Mapping the field of Industry 4.0 based on bibliometric analysis (Janik and Ryszko, 2020).

Janik and Ryszko (2020) adopted VOSviewertool for the visualization of the results of their bibliographic analysis. Industry 4.0, smart factory, smart manufacturing, intelligent manufacturing, design, model, algorithm, internet, internet of things (iot), iot, technology digitalization represent the most frequent keywords in the field. In their research four clusters were identified:

1) Smart factory and cyber physical systems (red coloured)
2) Internet of Things and cyber security (yellow coloured)
3) Data analytics (green coloured)
4) Additive manufacturing (blue coloured)

The other pillars of Industry 4.0 are also recognized in the semantic map, proving that interpretation of Industry 4.0 via its pillars is common among academics and the approach implemented in the report is correct.

The next step of the research is to identify the knowledge offered by Higher Education Institution to students. It would be expected that the knowledge offered is convergent with the one produced.

Research framework

Research methodology
Scientific efforts are important for Industry 4.0 development. Nevertheless, stimulation of Industry 4.0 development is also by the educational services. Students taught and trained in Industry 4.0 idea, methodologies and techniques use them in their work, develop them and contribute synergistically to dissemination of Industry 4.0 approach.

The goal of the research undertaken in the IE3 project is to identify and fill in the gap between education offer and expectation of industry in industrial management and engineering context. The research is divided into stages, and the first stage focuses on identification of the educational offer presented by European HEIs. The research was conducted in four European countries which are the partners in the project, namely Italy, Spain, Sweden and Poland.

The methodology developed for the research purposes is multistage and presented in the flowchart in Figure 9.

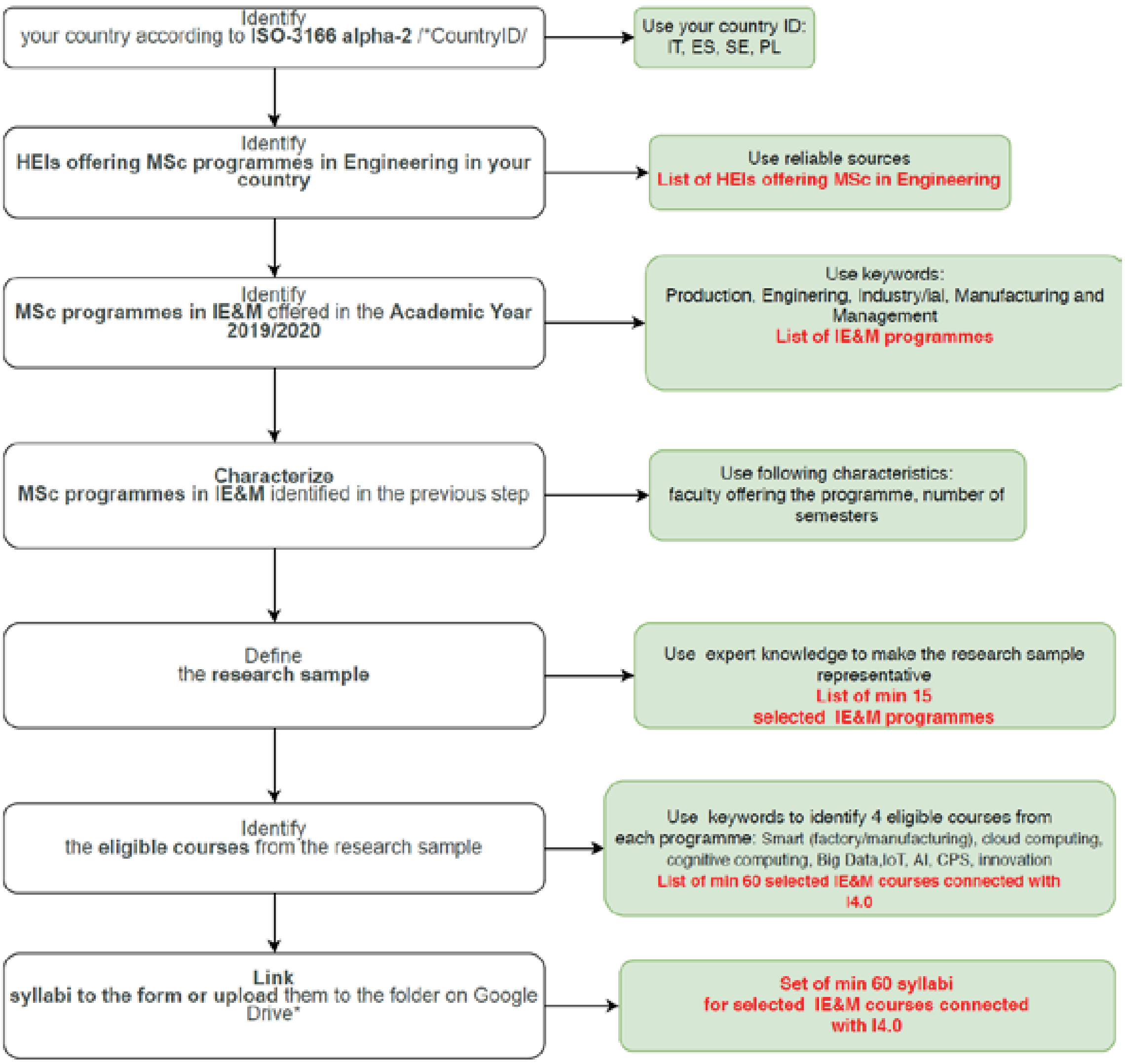


Figure 9 - The flowchart with a work plan for the first stage of IE3 research project

The research requires introducing some Initial data and constraints. They cover the scope of research: Higher Education Institutions providing 2nd level curricula on Industrial Engineering and Management. The curricula cover the Industry 4.0 scope and shape alumni who working as managers will be responsible for Implementing and disseminating Internet 4.0 solutions In companies.

The research is International and its consequence is that curricula from various countries that need to be included are settled in various education systems, having various titles and scope. The keywords sought for in the curricula title were set based on experts discussion and Include: **Production, Manufacturing, Industrial, Engineering + Management** (Management Is the common keyword). The curricula are to be identified and 15 of each country's set Is to be analyzed.

The curricula are to be analyzed In terms of content provided. The courses referring to Industry 4.0 are to be recognized and analyzed. To Identify the courses the set of keywords was defined basing on Industry 4.0 pillars and experts knowledge on courses provided at HEIs. It Includes: **Smart Factory/Manufacturing, Cloud Computing, Cognitive Computing, Big Data, Internet Of Things, Artificial Intelligence, Cyber-Physical Systems, Innovation.** There are 60 courses to be identified by each partner country and to analyze them the syllabi are to be provided to analyze their content for convergencies and divergencies.

Research results

The countries in the research are the project partner countries. The research teams were responsible for identification of IE&M programmes offered by HEIs. The results of the research conducted among HEIs in 4 European countries prove that Academia recognizes the need to equip managers with knowledge on industry, manufacturing and engineering (see Figure 10).

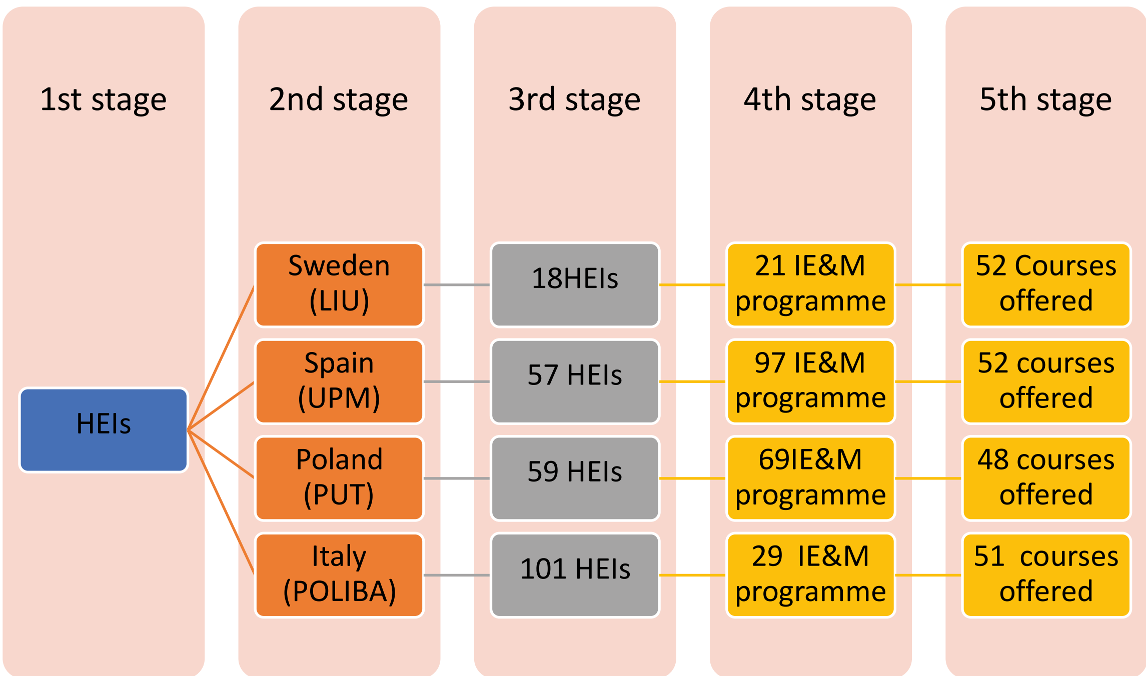


Figure 10 Quantitative results of the research on IE&M programmes selected by HEIs in selected countries

The total number of HEIs identified by LIU, UPM, PUT and Poliba on the basis of list of HEIs from partner countries is 235 HEIs. It is a product of the first stage which is the basis for further research.

At second stage there are selected IE&M programmes offered in the Academic Year 2019/2020. Programmes have been identified by the set of key words: Industry/Industrial & Management, Engineering & Management, Production & Management, Manufacturing & Management. The total number of programmes in each partner country varies between 21 and 97. It depends on the specificity of the education system in a given country and the variety of curricula offered at universities.

At next stage there are the eligible coursed from the research sample identified basing on key words related to Industry 4.0 (based on literature analysis briefly presented in the first part of the report) and including: smart factory/manufacturing, cloud computing, cognitive computing, Big data, Internet of things, Artificial intelligence, Cyber-physical systems, Innovation. The total number is 203 courses offered by HEIs in the scope of IE&M programmes at 2nd cycle of studies.

All masters-level courses in Poland take 3 semesters. In Spain, the number of semesters is different and varies between 2 and 5.5 with about 30% of the universities offering the possibility of obtaining a master's degree in just 2 semesters. In Sweden, the second-level courses last 4 semesters (except from integrated 1st and 2nd cycle courses which take 10 semesters). In Italy all masters-level courses take 4 semesters.

Despite of partners countries syllabi analysis also covers different European countries offering IE&M programmes at 2nd cycle such as:

- Belgium – 26 courses
- Germany – 26 courses
- France- 21 courses
- Finland – 15 courses
- Latvia – 11 courses
- Portugal – 11 courses
- Hungary – 9 courses
- Serbia – 8 courses
- Great Britain – 8 courses
- Netherlands- 7 courses
- Slovenia – 4 courses
- Republic of North Macedonia – 3 courses

The total number of courses from partner and remaining countries amounted to 352 courses.

The research sample of courses contains the courses related to Machine Learning, Artificial Intelligence, Robotics and Manufacturing, Automation, Data Mining, Advanced Manufacturing Technology, Industrial Internet of Things, Digital Business Innovation, Business Intelligence for Big Data, Digital Technologies for Industry 4.0, Virtual Prototyping, Smart Maintenance, Augmented Reality, Robotics and Cyberphysical Cystem, Cybersecurity, Internet of Things Sensors, Intelligent Manufacturing, 3D Printing.

The syllabi analysis on the data received was conducted with text mining methodology. The database with syllabi from Industry 4.0 associated courses available was created and the search for most often mentioned words and terms was made.

The results of the search are presented in the form of semantic map in figure 11a and figure 11b and figure 12. First diagrams (11a and 11b) presents relations based on association strength and second one based on fractionalization. The association strength method is used for normalizing the adjacency matrix of a network. Apart from a multiplicative constant, this method is identical to Eq. (6) in Van Eck and Waltman (2009). This option is selected by default.

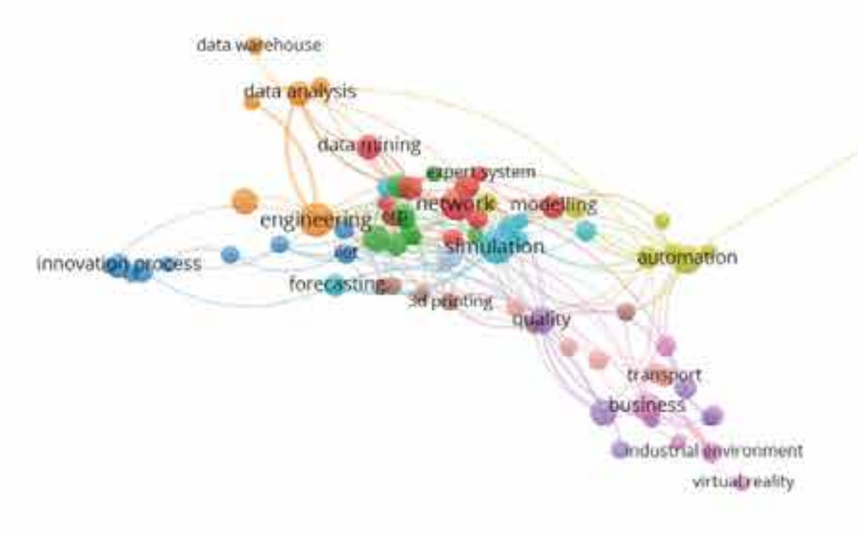


Figure 11a - Semantic map of courses connected with Industry 4.0 content based on association strength (network visualization of syllabi elaboration)

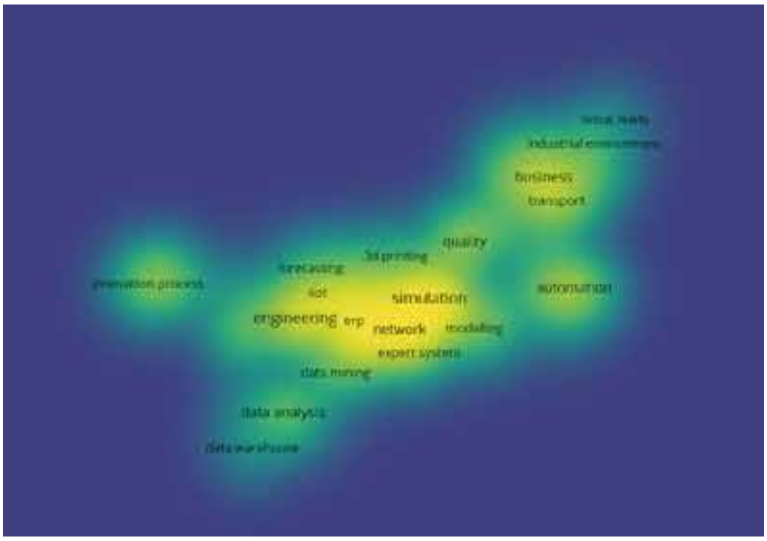


Figure 11b - Semantic map of courses connected with Industry 4.0 content based on association strength (density visualization of sllabi elaboration)

The map gives the idea of the core of courses connected with Industry 4.0 issues. The core includes aspects of engineering, data mining, automation, robotics simulation and clouds. The association with maintenance issues, cooperation innovation and quality was also identified, nevertheless its strength was lower. In the next figure the fractionalization method is used for normalizing the adjacency matrix of a network. Apart from a multiplicative constant, this method is identical to Eq. (13) in Van Eck and Waltman (2009).

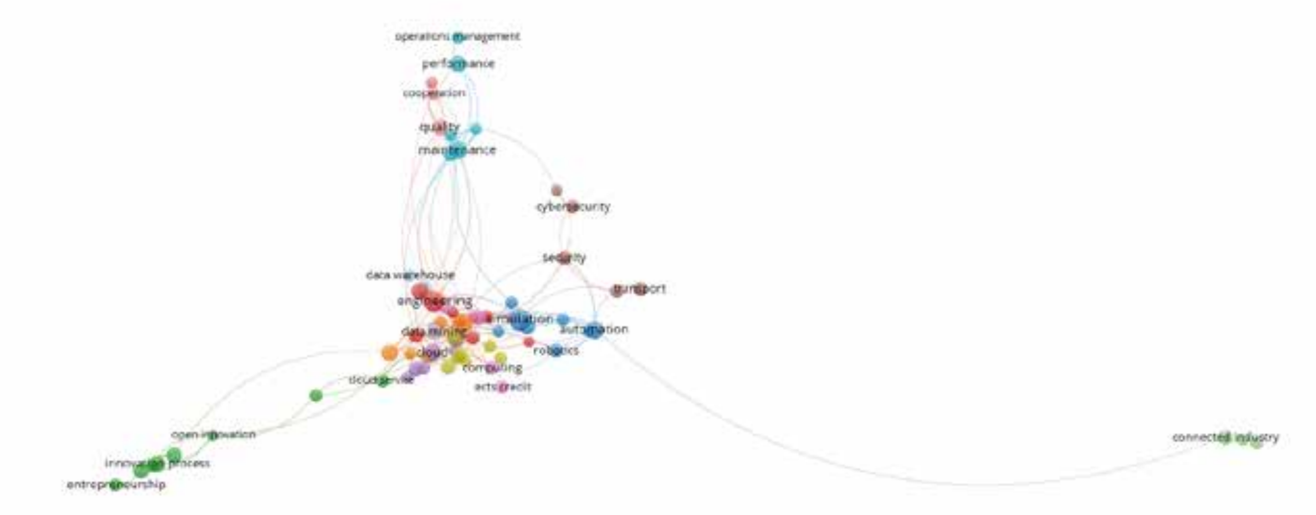


Figure 12 - Semantic map of courses connected with Industry 4.0 content based on fractionalization

The map presents a bit different approach grouping innovations and enterprenership; maintenance, quality and performance and core issues connected with Industry 4.0.

Generally, there are core clusters identfied within the courses content covering:

1) Automation issues,
2) Innovation,
3) Industrial robots,
4) Virtual reality,
5) Data analysis

Which is convergent with the clusters identified on the bases of literature review.

It can be seen that the names of the courses are moving towards increasing students' knowledge in the field of technological innovation and digitalization of the industry. There are curriculas that refer to smart manfacturing, smart company management, agile production systems which means that these aspects are more and more important for universities and become and essential part of their offer.

Statistical analysis of the content (based on syllabi collected) was also conducted to identify terms and concepts most often mentioned in courses description, as well as those least often mention. The results are to be used, together with results of further steps of the research, to design courses covering gaps identified in terms of quantity (terms and content mentioned rarely or not mentioned at all) and quality (perception of students and alumni).

The results of the analysis are presented in the Table 3.

Table 3 - Statistical analysis of syllabi

Word	Occurrences	Frequency	Rank
systems	686	1.5%	1
data	538	1.2%	2
management	531	1.2%	2
production	411	0.9%	3
design	400	0.9%	3

innovation	374	0.8%	4
knowledge	345	0.8%	4
industrial	312	0.7%	5
analysis	297	0.7%	5
control	278	0.6%	6
process	261	0.6%	6
processes	260	0.6%	6
manufacturing	259	0.6%	6
development	252	0.6%	6
information	244	0.6%	6
business	225	0.5%	7
models	219	0.5%	7
tools	215	0.5%	7
techniques	211	0.5%	7
engineering	209	0.5%	7
technologies	206	0.5%	7
project	203	0.5%	7
industry	188	0.4%	8
system	169	0.4%	8
simulation	162	0.4%	8
product	153	0.3%	9
technology	153	0.3%	9
applications	151	0.3%	9
digital	143	0.3%	9
planning	142	0.3%	9
concepts	141	0.3%	9
model	130	0.3%	9
projects	129	0.3%	9
machine	127	0.3%	9
application	125	0.3%	9
advanced	123	0.3%	9
technological	118	0.3%	9
networks	115	0.3%	9
services	110	0.2%	10
research	105	0.2%	10
cloud	105	0.2%	10
support	97	0.2%	10
enterprise	94	0.2%	10
decision	93	0.2%	10
quality	91	0.2%	10
automation	90	0.2%	10
skills	90	0.2%	10
modeling	87	0.2%	10
programming	85	0.2%	10
integration	82	0.2%	10
service	80	0.2%	10
virtual	79	0.2%	10
solutions	77	0.2%	10
supply	75	0.2%	10
environments	75	0.2%	10
implementation	75	0.2%	10
communication	75	0.2%	10
innovative	74	0.2%	10

software	74	0.2%	10
products	74	0.2%	10
social	73	0.2%	10
network	72	0.2%	10
processing	71	0.2%	10
computer	71	0.2%	10
organization	70	0.2%	10
maintenance	70	0.2%	10
computing	69	0.2%	10
methodologies	69	0.2%	10
value	68	0.2%	10
chain	68	0.2%	10
operations	65	0.1%	11
intelligence	63	0.1%	11
complex	62	0.1%	11
mining	62	0.1%	11
Logistics	58	0.1%	11
environment	55	0.1%	11
company	55	0.1%	11
companies	55	0.1%	11
linear	55	0.1%	11
discrete	54	0.1%	11
modelling	54	0.1%	11
integrated	53	0.1%	11
applied	53	0.1%	11
intelligent	53	0.1%	11
strategies	53	0.1%	11
technical	52	0.1%	11
cad	52	0.1%	11
structure	51	0.1%	11
algorithms	50	0.1%	11
strategic	49	0.1%	11
strategy	48	0.1%	11
iot	48	0.1%	11
problem	48	0.1%	11
analyze	47	0.1%	11
artificial	47	0.1%	11
resources	46	0.1%	11
robot	46	0.1%	11
regression	44	0.1%	11

The least often used terms (0.1% of total number of words used) suggest that the gap in courses offered content includes the following topics:

- functions (regression, linear, discrete)
- robot
- resources management
- artificial intelligence
- IoT (Internet of Things)
- data mining
- logistics

- strategies
- CAD (Compuer Aided Design)

Some of the topics listed can be covered by courses offered at the 1st level of academic education, qualitative research among students and alumni should indicate which skills and knowledge areas they feel comfortable with.

The number of universities in the countries surveyed, including both technical universities and other types of universities is significant. Similarly, the number of IE&M programmes is impressive. The question arises whether quantity of courses and programmes can be translated into the quality of teaching and the level of knowledge of students becoming future employees in manufacturing companies.

The other stakeholders important from education perspective is company. They offer training to their employees to improve their skills and increase their knowledge. To learn about training offered by companies the research was carried among companies settled in European countries. The number of answers is presented in the figure 13.

Questionnaire for Companies			
	Answers	**Minimum Target**	**Progress (%)**
Italy	11	6	183%
Poland	10	6	167%
Spain	14	6	233%
Sweden	7	6	117%
Other (AIM - ESTIEM - Madrid Network and Company partners)	33	24	138%
TOTAL	***75***	***48***	***156%***

Fig. 13 - Structure of the research sample

The surveyed companies represent European contries and operate on the global market. The locations and sites of the resondents are presented in Figures 14a and 14b.

Country	#
Spain	14
Italy	11
Poland	10
Germany	7
Sweden	7
The Netherlands	4
Slovenia	4
Portugal	3
Finland	2
Macedonia	2
United Kingdom	2
Austria	1
Belgium	1
Croatia	1
France	1
Hungary	1
Norway	1
Romania	1
Serbia	1
Turkey	1

Fig. 14a - Respondents: Countries of origin

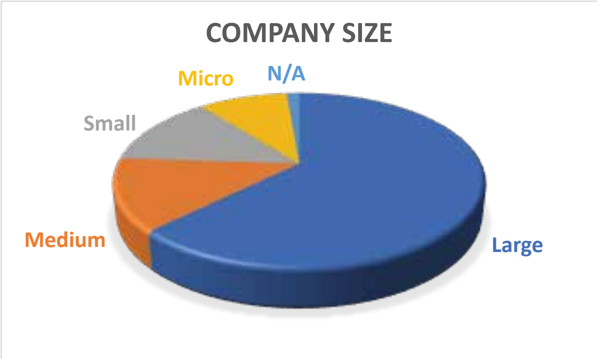
Country	City
Austria	Gölling
BELGIUM	BRUSSELS
Croatia	Solin
Finland	Helsinki
Finland	Espoo
France	Rodez
Germany	Munich
	Munich
	Munich
	Bremen
	N/A
	Berlin
	Wolfsburg
Hungary	Gemenа
Italy	Altamura
	BITONTO (BARI)
	Modugno
	Porto Sant'Elpidio
	Bari
	Bari (Italy)
	Milan
	Milan
	Milan
	Limena (PD); Modugno (BA)
Macedonia	Skopje
	Skopje
Netherlands	Amsterdam
	Many
	Amsterdam
	Rotterdam
Norway	Oslo
Portugal	Pinhal Novo
	Carregado
	ALVERCA
Romania	Bucharest
Serbia	Not applicable/Services

Company Production site location

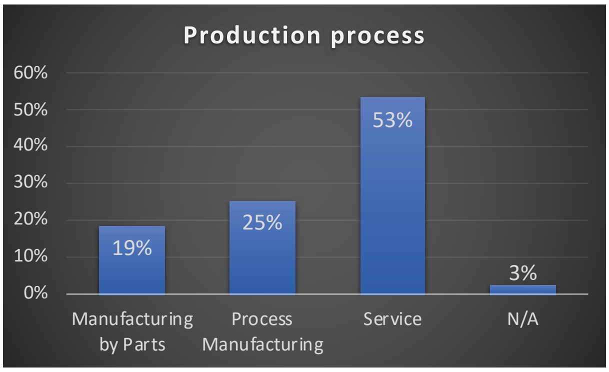
Country	City
Poland	Warsaw
	Poznań
	CZARNKÓW, POLAND
	Poznan
	Gadki near Poznan
	Posen
	Wloclawek
	Radom
	Poznan
	Kolo
Slovenia	Maribor, Slovenia
	Maribor
	N/A
	Maribor
Spain	Bilbao, Spain
	Avilés
	Sanmartzi
	AMOREBIETA
	Several cities in Spain (Avilés, ...)
	Madrid
	Gatika. (BasqueCountry)
	Madrid
	Barcelone
	N/A
	Bonares
	Derio (BIZKAIA)
Sweden	Linkoping
	Skärblacka but also ...
	Skärblacka but also other locations
	Mjölby
	Stockholm
	Stockholm
	Sweden
Turkey	Izmir, Turkey
United Kingdom	London

Fig. 14b - Respondents: Production site locations

The respondents represent various scopes and scales of activity, different sizes and capital structure. Detailed characteristics are presented in the figure 15 (referring to size, industry, structure of capital respectively).



large (staff 250 or more)	63%
medium (staff 50 or more but less than 250)	13%
small (staff 10 or more but less than 50)	13%
micro (no more than 10 staff)	9%
Not Available	1%



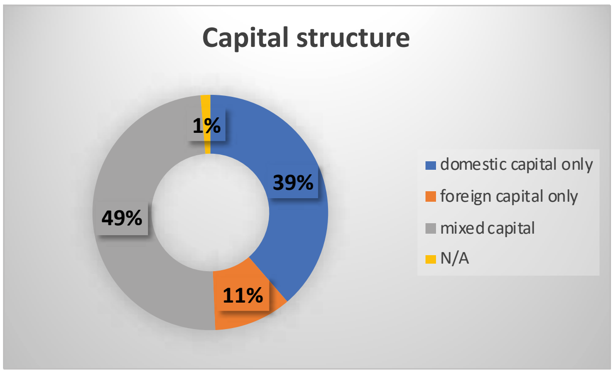


Fig. 15. Respondents: company's profile

The questionnaire included questions on the educational offer provided by the companies but also the demand and expectation. The hereby report covers issues connected with offer only.

Firstly, the comapnies were asked whether they organize training session and how they do that (with or without external professional support). The responses are presented in the figure 16.

		How are training sessions organized?			
		they are organized inside the company	they are based on external education offer	both previous options	no training sessions organized
Company size	Large	22%	7%	70%	2%
	Medium	25%	25%	38%	13%
	Small	50%	0%	40%	10%
	Micro	14%	0%	43%	43%

Fig. 16 Responses: How are training sessions organized

Generally, most large companies offer training and they use their own and external resources as well. Micro companies either do not offer trainings at all or exploit all possible options, organize them themselves and benefit from external educational offer. Small and Medium companies also offer trainings (about 90% of companies confirms the offer). Interesting thing is that medium companies benefit from external offer most of all the groups. They also organize their own training sessions and combine the offer. Hence, companies are aware of the importance of training sessions and they see that skills and knowledge can be provided in many ways.

Next question was about frequency of training. The answers are presented in the figure 17.

		What is the frequency of training sessions?			
		High (regularly, at least yearly)	Medium (at the recruitment stage and when strictly required)	Low (only at the recruitment stage)	no replay
Company size	Large	62%	32%	4%	2%
	Medium	30%	30%	20%	20%
	Small	10%	70%	10%	10%
	Micro	0%	57%	0%	43%

Fig. 17 - Responses: How often are trainings essions organized

The aswers pattern recognized is similar to the one discussed in the previous section. Large companies offer their trainings regularely, while the micro ones less frequently. Usually, training sessions are demand driven (organized when required). There were no questions on the reasons for such situation, but lack of resources (money, time, people) seems to be probable cause.

The issues under research were not only frequency and organization of training session, but also their content. Companies were to asses what knowledge and skills are provided during training session and at which level. The scale used was as presented in the table 4.

Table 4 - Agreement scale used in the questionnaire

"not offered (OFFER) or not required (DEMAND)"	0
"low"	1
"medium"	2
"high"	3
“don’t know”	*null*

The knowledge and skills listed in the questionnaire are coherent with the contemporary industrial engineering and management aspects analyzed in the context of HEIs offer. The consistency was required so that the data could be used further in the research. However, some additional aspects important from companies’ perspective were added to present the full picture of companies’ training offer. The answers are presented in the figure 18. The least offered skills are those connected with 3D printing and augmented reality, while the most often offered are those on safety, communication and team-work. The companies were not asked for reasons of such situation but law requirements and actual demand seems to be probable causes (safety training is periodic and obligatory, and team work and communication is universal, while 3d printing is specific professional activity).

It was also checked whether there are differences in training offer in manufacturing and service companies. The results of the analysis are presented in the figure 19. There were few significant differences, namely safety issues are more important in manufacturing companies, while communication and enrepreneurship is more important in service companies, probably due to specifics of the industries.

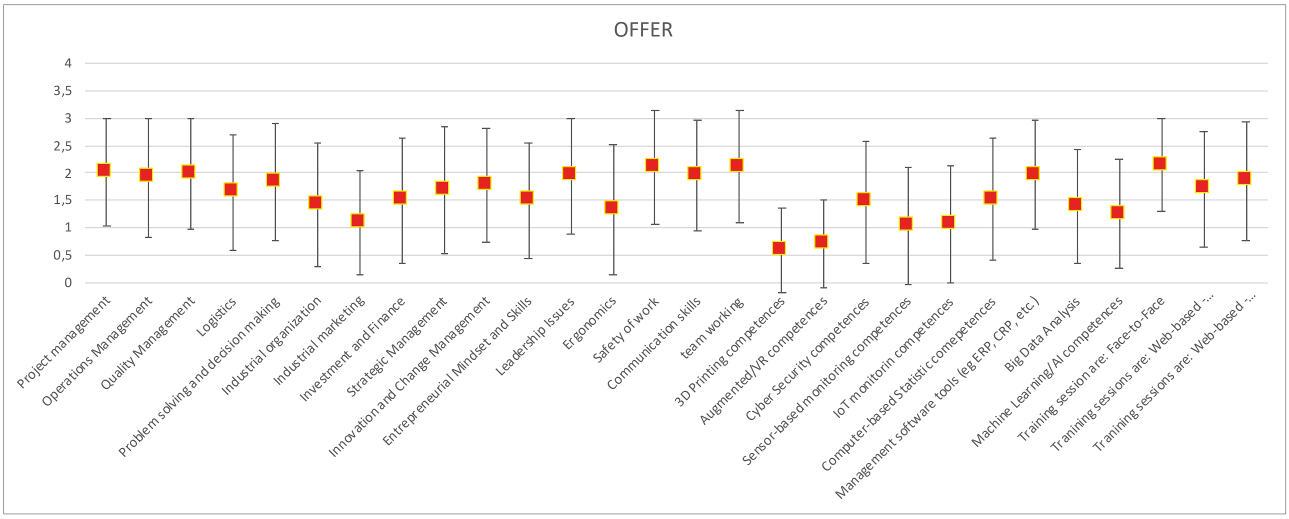


Fig. 18 - Content offered in companies' training sessions

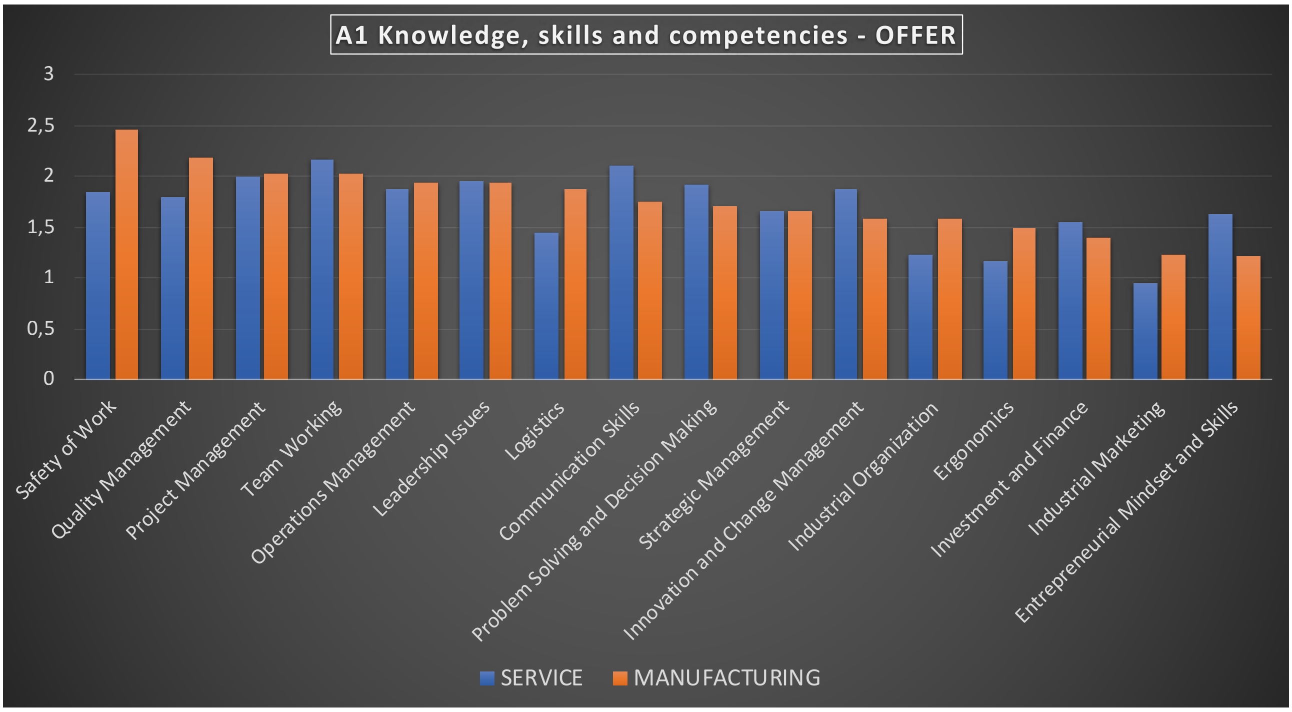


Fig. 19 - Content offered in companies' training sessions: by industry

Summing up, companies offer training to their employees. The offer is determined by law regulations and needs (demand), and constrained by resources available (time to prepare, organize and run training session, people to conduct them and money). Companies' training offer complements and develops issues included in HEIs offer.

Summary

After analysis of the courses the following conclusions can be drawn:

- There are no substantial divergencies between topics of academic research and educational offer of HEIs,

- Both academic research and educational offer refer to managerial and technical aspects of Industry4.0
- Importance of manufacturing technologies is stressed together with importance of data processing technologies
- Companies develop educational offer with respect to resources available.

The qualitative research gave the feedback on the content of courses offered and its convergencies and divergencies with academic research. Generally, the issues discussed in the courses are closely similar/the same as the ones presented in academic literature. However, some of the topics by academics are new areas of knowledge, thus they are not covered by higher education system. The research identified topics/ subjects by keywords in scientific publications and content of syllabi – the range and level of knowledge provided by HEI was not analyzed. Partially, this aspect will be covered by further stages of the project.

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