Basic Technologies and Models for Implementation of Industry 4.0

Karabegović, Isak

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Sarajevo, 5th - 6th October, 2023

Proceedings

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C O N T E N T S

PREFACE

The Academy of Sciences and Arts of Bosnia and Herzegovina (ANU BiH) continuously monitors and studies the development and implementation of new technologies in all industries. One of the latest contributions to these processes is the International Conference entitled ''Basic technologies and models for the implementation of Industry 4.0'', organized by the Department of Technical Sciences. Currently, the world is facing major changes. Research and development of innovation in new technologies, as well as rapid pace of implementation, especially digitalization and automation, have a major role in shaping the future world. The world has undergone a transformation with technological innovation that is constantly changing. It is necessary for all of us to adapt to the coming changes. A new era with all its challenges is ahead of us, a business climate limited by uncertainty, increased competitiveness, rapidly evolving technologies, infrastructure engineering, growing uncertainties, etc. Research seeks to understand the key challenges and opportunities that are accelerating in order to achieve strategic and competitive advantages. The development and implementation of new technologies is motivated by technical and economic reasons, such as: improving the quality of finished products (machining, etc.), reducing working hours (assembly processes), increasing the degree of homogeneity - constant quality (in all processes related to robotic application), increasing the speed of safety (in aggressive, flammable, explosive and other areas with a high degree of protection), reducing the required routine workforce and process repeatability, minimizing costs production and overall maintenance, meeting the requirements of the competition, as well as customer requirements. We are at the very beginning of the fourth industrial revolution. Industry 4.0 is a concept of production in which everything is networked, so that in the production processes of machines, devices or their sensors are connected wirelessly, but also connected to a system that can make decisions driven by a large amount of data. Although Industry 4.0 concept is being implemented in our environment, the concept itself is not yet widespread. It is expected that the implementation of this concept will improve and enhance all aspects and segments of human life. Within the fourth industrial revolution, a new value chain was formed, which primarily relied on the cyber-physical system (CPS) and its associated service, most often realized in the cloud (Cloud Computing). It is necessary to create a framework that describes the key issues and emphasizes possible answers. More precisely, it is necessary to provide a platform to encourage public-private cooperation and partnership on emerging issues related to the fourth technological revolution. The implementation of Industry 4.0 itself brings a change of business paradigms and production models that will be reflected at all levels of production processes and supply chains, including all levels of the workforce in the production process, managers, cyber-physical system designers, customers as well as end users. Major changes in all industries, including new business methods, transformation of production systems, consumption, delivery and transport itself, are happening due to the implementation of new technological advances such as: robotics and automation, internet of things (IoT), big data, 3D printing, smart sensors, radio frequency identification (RFID), virtual and augmented reality, artificial intelligence, advanced security systems, etc. In Industry 4.0, the epithet ''smart'' has become a popular phrase, so that the production process, machines, cars, household appliances, *houses, and production environments get the epithet smart. The meaning of smart is easiest to define as a combined ability to create, share and act on data. Industry 4.0's strategy is reflected in the adaptation of industrial production supplemented by smart automation. These include methods of self-automation, self-configuration, self-diagnosis, conversion, and intelligent decision making. However, there are many challenges on the way to implementing Industry 4.0, such as changing business bias, resource planning, legal issues, security issues, standardization, and other issues. Industrial production will undergo rapid fundamental changes so that some jobs will completely disappear and many others will be created, i.e., a significant part of current jobs will be changed in some way. Industry 4.0 has an impact on companies by increasing automation and optimization, constant monitoring, personalization and customization, data mining, virtual reality, improving the work environment, increasing the use of robotics, etc. The implementation of Industry 4.0 in companies requires employees who are capable for the tasks of the future and who are certainly willing, able and educated to develop the future. We must note that the core technologies of Industry 4.0 are currently applied only in the manufacturing industry. However, they will not remain only in the industry, but rather expand to hospitals, supply chains, logistics, security systems, smart devices, etc., so we can rightly say that they will be more and more present in the future. The very concept of Industry 4.0 represents a great advancement in industrial production, as well as in other aspects of the company's business. Developed countries around the world have their own strategies and have embarked on the implementation of Industry 4.0 concept, in order to increase their competitiveness in the global world market. In the Western Balkans, the concept of Industry 4.0 is a relatively new concept, although most SMEs understand the benefits of smart manufacturing and are aware of new trends in the industry, and intend to gradually introduce smart solutions, methods and technologies. We need to mention only a small number of SMEs currently implementing Industry 4.0 concept. For companies in the Western Balkans, the cost of implementation and the high complexity of the core technologies of Industry 4.0 present major challenges, but companies are interested in smart manufacturing because they believe the following four areas are most important to increase competitiveness: better customer coordination, better product quality, lower production costs and better compliance with customer specifications or regulatory requirements. We must note that the success or failure of the implementation of Industry 4.0 in all countries in the world, including the Western Balkans, lies in the hands of all participants in the chain, from producers to end users or customers.*

The Academy of Sciences and Arts of Bosnia and Herzegovina thanks the Society for Robotics of Bosnia and Herzegovina, the Foreign Trade Chamber of Bosnia and Herzegovina, and the Chamber of Economy of the Federation of Bosnia and Herzegovina for co-organizing the conference. The organizers of the conference hope that the scientific and professional public will especially benefit from the vast knowledge and experience that experts in this field have summarized in their presentations.

On behalf of all those who participated in organizing the conference and publishing the Proceedings, I would like to thank all the employees of the Academy of Sciences and Arts of Bosnia and Herzegovina for their great commitment to the success of this conference.

Sarajevo, September, 2023

Corresponding member Isak Karabegović, editor
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Engineering Skills for Intelligent Manufacturing

Vidosav D. Majstorović*[1], Radivoje Mitrović[2], Žarko Mitrović[3]

Abstract: *The terms ''digital manufacturing'', ''Industry 4.0'', ''smart factory'', ''intelligent/smart manufacturing'', or ''factory of the future'' represent the same concept today. This means that individually automated machines and separate processes have experienced the full integration of all of its elements into a single digital system. This paper presents the elements of the engineering skills for model of Industry 4.0.*

Keywords: *Industry 4.0, Skills, Engineering.*

1. Introduction

Global trends that have a great influence on the development of a new generation of technological systems, based on the concept of Industry 4.0, are: (i) population aging, (ii) minority populations and their inclusion in manufacturing flows, (iii) reduction of natural resources, (iv) imagination and mobility of young talents, (v) digitization of manufacturing and supply and sales chains, their connection and cyber threats, and (vi) progressive global warming. All these facts have a greater or lesser impact on the development of technological systems, including the development and application of Industry 4.0 model [3,4].

At present, the main components of intelligent manufacturing are: (1) semantic multimodality - presentation of different information in the factory - attributes with a hierarchical structure, relations, tables, graphs and entities; (2) multidimensionality - information in several dimensions must be presented and recorded - description of business processes and technological operations performed at different levels of the digital manufacturing structure; (3) multi-granularity - access to sensor and equipment data contributes to the assessment of the technological process, and if necessary, provides the possibility of its regulation and control; (4) transparency and integration. Distribution of information between units - manufacturing automation, quality control, enterprise resource planning system, etc. - should be integrated while maintaining the systemic nature of records [1,2,4].

*[1,2,3]University of Beograd, Faculty of Mechanical Engineering, 11000 Belgrade, Serbia
E-mail: vidosav.majstorovic@sbb.rs

Digital manufacturing is causing changes in various areas, both within the industry itself and outside it, i.e., all stakeholders. One of the most important segments of the development and application of this concept in industry is education for digital manufacturing, and within this segment is engineering education. Research shown in [1, 2] indicates that, from the point of view of digitalization, educational systems in developed countries have serious shortcomings, which are reflected in the following: (i) untimely monitoring of trends related to digital manufacturing in terms of required skills and, on the other hand, (ii) clearly defined requirements for advanced jobs by the industry. If we analyze the changes in the knowledge required for digital manufacturing in the last decade, in relation to the workplace and the manufacturing function itself, we come to the conclusion that the requirements for new skills in the workplace have increased more than four times. This is due to the fact that machine tools have become Cyber-Physical Systems (CPS), with completely new features.

On the other hand, research presented in [2] shows global trends in the USA and the EU in changing the character of skills for digital manufacturing, in the period 2016-2030. The mentioned changes relate to a significant reduction in the need for manual and basic cognitive skills, compared to, for example, technological skills, which will increase by more than 50%. This means that the structure of knowledge in this field is changing, from classical engineering to integrated knowledge of mechanical engineering, electrical engineering and computer science.

2. Skills for the Technological Systems of the Future

New generations of technological systems require new knowledge and skills, because new paradigms and models are being introduced into manufacturing: (i) zero-waste manufacturing, (ii) global agile supply chain networks, (iii) energy and resource efficiency, (iv) mass personalization, (v) integration - horizontal and vertical, and (vi) data security and accuracy [5-8].

Our research shows that the basic skills for intelligent manufacturing are defined as[6-8]:

- digital literacy as a holistic skill to interact, understand, apply and even develop digital technological systems, technologies used for the systems, and applications and tools used in the systems
- effective communication skills with people, IT and AI systems, through different platforms and technologies,
- ability to use and design new solutions for AI /ML and data analysis with critical interpretation of results,

- creative problem solving by analyzing big data sets and technological possibilities in smart manufacturing systems,
- cyber security, privacy and data/information protection, reflect the rapidly growing digital model of the manufacturing value chain,
- strong entrepreneurial mindset, including proactivity and the ability to think outside the box,
- physical and psychological ability to work safely and efficiently with new technologies,
- the ability to deal with the increasing complexity of multiple demands and simultaneous tasks,
- an intercultural and interdisciplinary, inclusive diversity orientation, in order to respond to new challenges arising from a diverse manufacturing workforce, and
- openness to constant change and transformational skills that constantly question the status quo and initiate the transfer of knowledge from other domains.

As the previous analysis shows, all skills for intelligent manufacturing can be grouped into two units: (i) technical-technological (first five groups), and (ii) socio-economic (second five groups).

When we have defined the characteristics of the required skills, the following questions are asked and relate to everything that needs to be solved in the context of application in industry, namely[5-8]:

- openness to constant changes and transformational skills that constantly question the status quo and initiate the transfer of knowledge from other domains,
- increased investments in employee education in order to reach the full potential of new technologies,
- support policies to promote education and training of employees in the organization,
- provide a person who will deal with career development for manufacturing,
- develop new profiles with technical expertise complemented by general knowledge,
- use digital technologies for innovative delivery of education and training,
- support social mobility in manufacturing,
- ensure that relevant skills are trained,
- increase the importance of professional technical education and training with work in the organization, and
- encourage collaboration to address skills development needs.

In this way, we connect and integrate the knowledge and methods that form the framework for intelligent manufacturing.

3. Jobs in Intelligent Manufacturing

Already today, in technologically advanced companies, which represent examples of intelligent manufacturing, we have workplaces that support these manufacturing models, and in the following text, we list some of them [9-12].

They are responsible for implementing digital twin technology that enables predictive maintenance, which helps to identify potential failures in equipment before they occur. **Digital twin engineers** must actively collaborate with multiple departments and stakeholders, such as product design teams, operations teams, data scientists, and software engineers, to ensure the digital twin is aligned with the physical product and its context.
Digital twin engineers must have a deep understanding of physical systems, IoT devices, programming languages, and data analysis tools. They must also be able to reverse engineer complicated systems and evaluate how to engineer digital twins for them.
Overall, digital twin engineers play a critical role in bridging the gap between the physical and digital worlds, helping companies optimize their operations, reduce costs, and improve customer experience.
Additionally, digital twin engineers should have strong communication skills, the ability to work in a team, and the capacity to adapt to changing technologies and processes. They must be able to prioritize tasks and manage time effectively to ensure efficient product development and implementation. They must also stay up-to-date with the latest industry trends and technologies related to digital twin engineering.

Data analysis and modeling skills for **predictive supply chain analysts (PALs)** should also include a deep understanding of supply chain management, logistics, and industry trends. They must have strong communication and collaboration skills, as they often work with various stakeholders across different departments to ensure seamless supply chain operations. PALs must also be able to adapt to new technologies and processes, be proficient in project management, and have a good understanding of regulatory requirements and compliance. Furthermore, PALs should be able to identify and mitigate risks in the supply chain, including disruptions caused by unforeseen events such as natural disasters or geopolitical events. They should also be able to optimize inventory management and warehouse operations, as well as analyze supplier performance to ensure the timely delivery of goods.PALs need to be able to develop and implement strategies to reduce waste, lower costs, and improve overall efficiency in the supply chain. Overall, PALs play a crucial role in enabling organizations to leverage the power of digital tools to transform their supply chain operations, helping them gain a competitive advantage in the marketplace.PAL helps companies achieve optimal inventory and supply chain management under current and anticipated demand scenarios.

Some of the important skills for PALs should include:

- Data analytics and statistical modeling
- Forecasting techniques and demand planning
- Knowledge of transportation modes and freight management
- Supplier relationship management
- Understanding of financial forecasting and budgeting
- Familiarity with e-commerce platforms and omnichannel logistics
- Effective communication and collaboration skills
- Adaptability and agility in dealing with change and uncertainty
- Ethical decision-making and compliance with regulations.

PALs should also continuously update their skills and knowledge to keep up with the evolving technology landscape and changing business needs. They should be proactive in seeking out opportunities to learn, network, and build their professional development.

Robots team coordinators (RTCs) also work closely with programmers and engineers to develop robot control systems and ensure that robotic equipment is properly maintained. They are responsible for identifying areas where robotics can be integrated into the manufacturing process to improve efficiency, reduce costs and enhance product quality. Another critical aspect of an RTCs' role is to ensure that human workers are trained in the safe and effective operation of robots. They develop training programs and help workers become comfortable with new technologies, so that they can effectively work alongside robots. People skills are imperative for RTCs to possess, since these professionals must be able to manage and motivate teams composed of human workers and robots. They must be able to communicate effectively and work collaboratively with individuals from different departments, including engineering, operations, and human resources. As automation and robotics increasingly become a critical part of the manufacturing industry, the demand for RTCs is likely to grow. This new generation of manufacturing professionals must be able to adapt to this rapidly-evolving landscape while making sure that human skills are complemented by the technology they create.

Some important skills for RTCs should include:

- Strong analytical and problem-solving skills to identify areas where robotics can be integrated for maximum benefit
- Strategic thinking and planning skills to develop long-term plans for implementing robotics in manufacturing or assembly environment
- Technical expertise in robotics, automation, and machine learning
- Familiarity with programming languages such as C++, Python, or Java
- Excellent communication and interpersonal skills to work collaboratively with cross-functional teams and effectively communicate complex technical concepts to non-technical stakeholders
- Knowledge of industry regulations and safety standards for working with robots
- Ability to manage multiple tasks and prioritize competing demands to meet project deadlines.

Overall, RTCs must be able to balance the needs and capabilities of robots and humans in order to effectively integrate robotics into the manufacturing process. They must have a deep understanding of how robots operate, and how they can be programmed and trained to work alongside humans. Additionally, they should be able to identify opportunities for automation and use data analysis to optimize the performance of robotic systems.

With a wealth of customer data at their disposal, companies have started using it to create customized customer groups, leading to a demand for professionals known as Digital Sales Managers (MDPs).
MDPs evolved from the product manager career.
Their key responsibilities are to identify and create new product offerings for clients, which are fully digitally rounded - the so-called smart products, and virtually available to the client, making them completely different from the physical products that a traditional company produces.
MDP is responsible for contributing to the expansion of new digital offerings in the company's portfolio of smart products.

Digital Sales Managers (DSMs) have become increasingly important in today’s digital age, where companies are using customer data to create personalized marketing and sales strategies. They are responsible for identifying new opportunities for digital products and services that can be developed and marketed to customers. In addition to identifying new product opportunities, DSMs also work closely with cross-functional teams to develop and launch new digital products. This involves collaborating with designers, developers, and product marketers to create products that meet customer needs and align with the company's overall business strategy. DSMs must have a strong background in digital sales and marketing, as well as experience in product management. They should be familiar with the latest digital technologies and trends, and have a deep understanding of customer behavior and needs. Strong analytical and problem-solving skills are also critical, as DSMs must be able to analyze complex data sets to identify opportunities and develop effective sales strategies. DSMs play a critical role in driving the growth of digital products and services in today's market. They must be able to adapt to the rapidly-changing world of digital sales and marketing, and have a deep understanding of how to leverage customer data to increase sales and growth.

The key skills required for DSMs include:

- Sales and marketing: DSMs must be able to identify new opportunities for digital products and services and develop effective sales and marketing strategies to promote them to customers.
- Analysis of customer behavior and experiences: DSMs must have a deep understanding of customer needs and behavior in order to develop products that align with customer preferences and thus increase sales.
- Communication: Effective communication skills are critical for DSMs to collaborate with cross-functional teams, communicate project updates, and engage with customers.
- Networking: DSMs must be able to build and maintain professional networks to identify new business opportunities and partnerships.
- Cooperation: DSMs must be able to work effectively with cross-functional teams, including designers, developers, and product marketers, to develop and launch new digital products and services.
- Client management: DSMs must be able to build and maintain strong relationships with clients to ensure customer satisfaction and increase sales.
- Social skills: DSMs must be able to work effectively with individuals from diverse backgrounds and cultures and build strong professional relationships.
- Change management: DSMs must be able to navigate and drive change within a company, including shifts in business strategy or product offerings, to enhance growth and remain competitive.
- Project management: DSMs must be able to oversee the implementation of new digital products and services, including managing timelines, budgets, and ensuring successful launches.

As automation technology advances and more companies begin to adopt drones and other automated equipment, new roles will emerge to manage and coordinate the data generated by these technologies. One such role is that of a

drone data coordinator (DDC), who will be responsible for overseeing the use of drone fleets and managing the data that they capture. The DDC role will require a combination of technical and managerial skills, including:

- Proficiency in project management: DDCs will be responsible for overseeing the use of drones on construction sites and ensuring that they are used safely and effectively to achieve project goals.
- Resource and equipment management: DDCs must be able to manage fleets of drones and other automated equipment, ensuring that they are properly maintained and utilized to maximize efficiency.
- Knowledge of data management: DDCs will be responsible for managing the data collected by drone fleets, including organizing, analyzing, and reporting on the data.
- Networking with service providers: DDCs may be responsible for sourcing unmanned drone service providers, negotiating contracts, and managing ongoing relationships with service providers.
- Executive responsibility: In some companies, the DDCs role may involve executive-level responsibilities, such as developing and implementing strategies to expand the use of drones in the company's lifecycle data management model.
- Overall, the DDCs role highlights the growing importance of data management and automation in the construction industry, and underscores the need for skilled professionals who can manage and coordinate these technologies effectively.

The key skills required for a DDC role include:

- Data lifecycle management: DDCs must have a deep understanding of data management principles and be able to manage all aspects of the data lifecycle, including collection, storage, analysis, and reporting.
- Optimization of resources: DDCs must be able to optimize the use of drone fleets and other automated equipment to maximize efficiency and productivity on construction sites.
- Analytics and communication: DDCs must be able to analyze and interpret data from drone fleets and communicate insights effectively to stakeholders.
- Networking and automation: DDCs must be skilled at building and maintaining professional networks, as well as leveraging automation technologies to improve data collection and analysis.
- Client management: DDCs must be able to build and maintain strong relationships with clients, ensuring that their needs are met and that they are satisfied with the services provided.
- Coordination and cooperation: DDCs must be able to coordinate with cross-functional teams, including drone service providers and other stakeholders,

to ensure that data collection and analysis is integrated effectively into overall project planning and execution.

- Change management: DDCs must be able to navigate change in the industry, including shifts in technology or strategic priorities, and adapt their strategies accordingly.
- Project management: DDCsmust be able to oversee the implementation of drone fleets and other automation technologies on construction sites, including managing timelines, budgets, and stakeholder relationships.

4. Conclusion

The application of Industry 4.0 model includes forty-five elements, whereas SMEs model in the field of manufacturingincludes eighteen elements.
The application of this model requires detailed knowledge and skills, which is specifically presented in the work.
Therefore, organizations that realize the elements of Industry 4.0 must also have specific workplaces, some of which are analyzed in this paper.
Our research in this area in the future will be related to defining the curriculum for intelligent manufacturing, based on our research in this area so far [3,4].

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Occupational Safety when Accessing Machine Remotely

Viktorijo Malisa[*1]

Abstract: *Machines have been equipped with the technical capabilities to send and receive data over networks for a long time. Today, not only machines, but entire production systems are networked worldwide to take advantage of information technology. Remote access to the machine is increasingly used to commission the machine, diagnose faults, adapt it to production, update functions and operating systems, or even have a machine repaired remotely by a specialist. However, the type of remote access must be tailored to the specific machine and therefore described in detail in the machine documentation. The special feature of remote access is that it combines cybersecurity with machine safety and occupational health. This requires that both the machine operator and the remote maintenance service provider are integrated into the respective organizational structure. The aim of this article is to describe the technical requirements for the secure implementation of remote access to machine controls and to highlight the necessary normative, organizational and preventive security measures.*

Keywords: *Occupational safety, OT-safety, remote access, remote maintenance, IT-security*

1. Introduction

With the Industry 4.0 initiative and the associated increasing digitalization of all technologies, machines and production processes, remote services have also evolved. Remote access to machine controls, IT systems, servers and computers is primarily used for remote control, remote monitoring and maintenance work.[13] Efficient service, fast troubleshooting and expert system diagnostics from a distance enable the operator to minimize downtime and provide the machine manufacturer or system integrator with efficient remote support, especially during the warranty period. Remote maintenance has gained tremendous importance due to the globalization of markets, technological advances in digitalization such as the Internet of Things (IoT), cloud services, video conferencing technologies and remote access software, and most recently increased global crises and supply chain disruption. However, in the context of remote maintenance, there are not only advantages, but also threats and dangers, so that technical and organizational prerequisites must be created and special

[*1]AUVA Allgemeine Unfallversicherungsanstalt, Vienna
E-mail: viktorijo.malisa@auva.at

security measures must be observed.Due to frequent cyberattacks through remote connections on production systems [7], IT security measures must be adapted to the systems in use [8].
Remote maintenance is not explicitly defined in the Machinery Directive 2006/42/EC, which is still valid. However, more and more established standards are being supplemented by the topic of remote maintenance and safety of IT (information technology) and OT (operational technology). For example, the current C standard EN ISO 10218-2 ‘’Industrial robots - Safety requirements - Part 2: Robot systems and integration’’ deals in detail with the topic of remote access to the robot controller, as well as the Technical Report CEN ISO/TR 22100-4:2021, ‘’Safety of machinery - Relationship with ISO 12100 - Part 4: Guidelines for machinery manufacturers on the consideration of related IT security (cyber security) aspects’’, which establishes the relationship between EN ISO 12100 ‘’Safety of machinery - General principles for design - Risk assessment and risk reduction’’ and cyber security.

2. ‘’Remote Access’’ Operating Mode

Remote access to a machine is when a person connects to the machine control via an electronic device without being able to see the machine and its surroundings. For example, the production equipment is on the ground floor and the office area of the technical department is above the production hall. If the technician (see Fig. 1, item 3) connects to the machine (see Fig. 1, item 1) via the company’s internal network (intranet), this is also referred to as remote access, just as when the remote maintenance specialist (see Fig. 1, item 2.) is in another location, in another country, and can access the machine control via a connection. It often happens that the production manager (see Fig. 1, item 4.) wants to view the machine’s data from the home office via the Internet or directly from a meeting on the company premises via W-LAN, so this operating mode is set up.

Basically, the following services are performed remotely by specialists (modified according to [14]):
1. In the remote access operating mode

- Diagnosis of the software
- Error analysis
- Production monitoring
- Inspection, data analysis and data transmission
- Training of operating and maintenance personnel
- Regular drills for all departments involved, scheduled drills as well as extraordinary drills after installation of new hardware and software

2. In remote control mode:
   - Starting and stopping certain functions (heating up, cooling down, emptying, feeling up, etc.)
   - Starting and stopping the machine

3. In remote maintenance mode:
   - Remote parameterization (changing adjustable parameters)
   - Software patch and updates (installation of new programs)
   - Commissioning (transfer of all software)
   - Maintenance support, retrofitting, support
   - Malfunction management, machine diagnosis (intelligent error detection, error codes with stored measures)
   - Installation of new functions

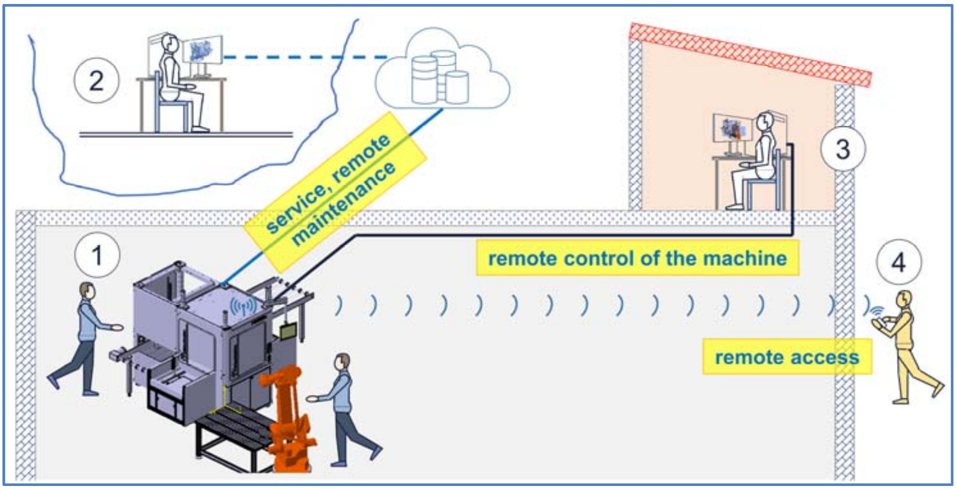

Figure 1. Remote access to the machine
1- machine, 2- remote maintenance specialist,
3- remote control of the machine, 4- remote access to the machine

Remote access, remote control and remote maintenance are operating modes that are integrated into the machine control system and are described in detail in the documentation of the respective machines. These operating modes are also taken into account in the risk assessment, whereby both occupational safety and cyber safety are taken into account (see Fig. 3). These operating modes can be integrated into the system control by the machine manufacturer or by a system integrator. Operating modes are secured, for example, with a key switch, a chip card and/or an access code. It is recommended to provide multiple authentications. In addition, the operating instructions must contain information

on ''which user groups are granted remote access to the machines at what time, for what period of time and with what rights. Remote access must be prevented at a time when the machine is performing critical functions'' [1].
The documentation also specifies how remote maintenance is to be carried out. The machine manufacturer or system integrator trains the staff for remote services so that they are able to prepare the machine for remote access, organize the connection and track and document the communication. With the commissioning of the machine/production system, remote services are also tested and adopted by the operator.
The remote services can be carried out passively or actively by the remote maintainer. Passive remote maintenance is carried out in such a way that a remote connection is established to the trained specialist on site at the machine. The specialist at the machine has, for example, AR glasses (augmented reality glasses), a smartphone, a headset, a tablet, a PC with monitor or a display at the machine with which communication with the remote maintenance specialist can be established. The remote maintenance specialist gives instructions and the specialist on site carries them out.
Active remote maintenance means that the maintenance specialist can directly intervene in the control system and make changes.
The change of parameters on the safety elements or the change of the safety control system can be suggested by the remote specialist, but must be confirmed by the specialist on site at the machines.

3. Connectivity

In order for remote access specialists to access the machine control at an operator's site, a secure and stable connection must be established, regardless of location, and usually across countries.A connection can technically be established in various ways, the most common being via the internet VPN (see Fig.2). As a rule, a VPN line will be established by the machine operator, IT/OT specialists, from the inside to the outside. The data traffic is encrypted, established security protocols are used and only required IP and ports are released. The remote access area is specifically restricted via the firewall rules.
In production systems that consist of several machines and have integrated higher-level controls, it is recommended to install a uniform remote access system for all controls. The components for this should be designed redundantly and with high availability and should only be used for remote access.
Remote maintenance components, equipment and software should be tested every six months. Unscheduled remote maintenance tests are particularly necessary when new employees are added to the remote maintenance team, e.g., when there is a change of personnel at the machine, in maintenance, in the

IT/OT department and when new hardware or software is used in the operator's company network and by service providers.

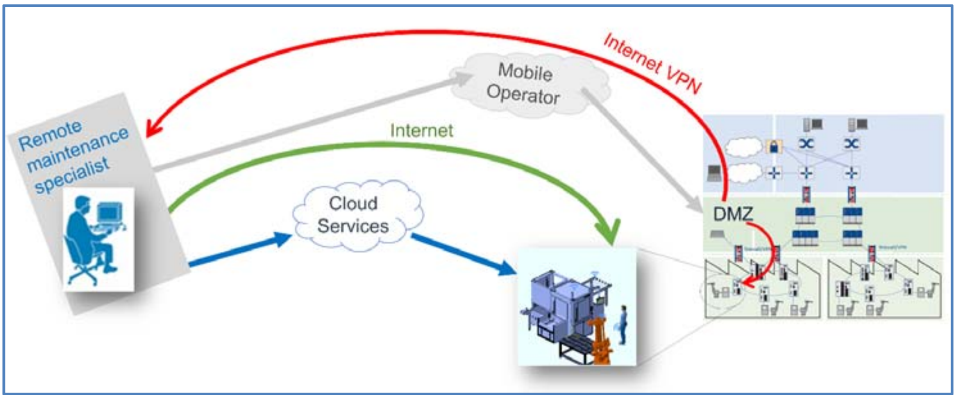

Figure 2. Connections from remote location and the machine

As part of the tests, the roles of all parties involved, communication among each other, possible process disruptions as well as exceptional situations such as interruption of the internet connection, timeout of remote access, connection with long delay time, failed installation of new user software and import of backup software to the machine are tested.
A connection can also be established via cloud services. Machines are deposited with access data on a platform and remote specialists are registered with their access data. The responsible employee of the operator is given admin rights and can create remote maintenance jobs. It is also possible to dial in via a telephone line and establish a direct ad-hoc connection via the internet using various software tools. For the connection to the machine control and for the remote maintenance operating mode, such connections are considered insecure and are therefore not recommended.

4. Risk Assessment

Cyber-attacks on companies are steadily increasing. Attacks on corporate networks via the internet pursue different goals, such as disrupting production processes, inflicting targeted damage or even stealing know-how. If a hacker succeeds in accessing the machine via the remote connection, he is virtually sitting in the middle of the machine operator's IT network, making it easy for him to attack the IT network from the inside and infect it with malware. One measure would be to implement network segmentation per machine to be maintained, so that only the respective machine can be accessed via the remote connection and further intrusion into the IT network is made more difficult.

Based on the risk assessment, cyber security measures must also be implemented (see Fig. 3). The operator is obliged to carry out a new risk assessment in case of hardware and software changes as well as updates and to implement risk-reducing measures if necessary.

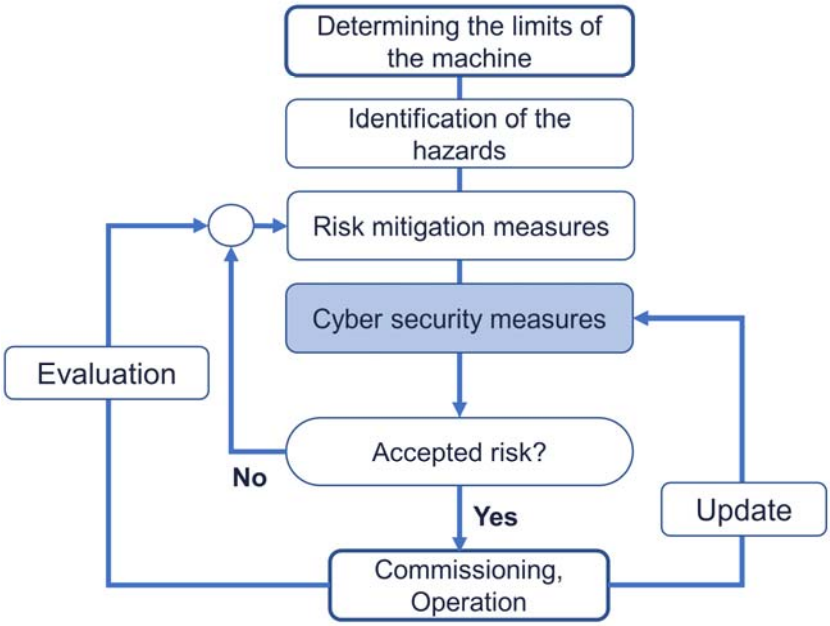

Figure 3. Risk assessment process with integrated cyber security

Remote access can cause some of the following dangers:

- incorrect configuration of the IT network leads the remote maintenance specialist to the wrong machine;
- incorrect configuration of the IT network allows the remote maintenance specialist to access the network outside the machine concerned;
- a premature maintenance leads to a partial or complete failure of machine functions;
- an update or modification of the machine control system leads to further unforeseeable malfunctions;
- malware is intentionally or unintentionally installed on the engineering PC and the machine control via the remote maintenance connection;
- misunderstandings in communication lead to unpredictable movements of the machine and damage to machine components or even injury to on-site maintenance personnel;

According to [1], [3] and [4], in order to establish a secure connection for accessing and performing remote maintenance, the following should generally be observed:

- Remote access should pass through a firewall and only allow access to the appropriate IP address and specific port. Any attempt to access other IP addresses must result in termination of the remote access.
- Remote access must be limited to the machine in question.
- Remote access must be activated by the operator's personnel.
- Secure authentication methods, such as current certificates, must be used for the software.
- The implementation of two-factor authentication is advisable, i.e., the proof of identity of a remote maintenance specialist should be done by a combination of two independent and different components (e.g., web access, personalized cards, fingerprint, smartphone, etc.).
- The devices and their data protection capabilities must be verified by routine validation tests on the network.
- A restriction of the connection to only one logged-in remote maintenance specialist at a time shall be implemented.
- Monitoring of accesses and continuous logging as well as their archiving by the operators of the industrial facility are essential.
- Only secure protocols such as IPSec, SSH or SSL/TLS should be used for communication, and always the latest version.
- Remote maintenance must be carried out in accordance with the operating instructions of the machine concerned.
- Encryption of data transmission should be implemented for remote maintenance; in addition, the following is recommended:
  - Remove malicious traffic before decryption (use of Threat Intelligence Gateway).
  - Use active SSL encryption
  - Use a stand-alone device
  - Protect plaintext data using intelligent data masking systems.

5. Use Cases

5.1 Special machine integrated in a production system

The machine is integrated into a production line and a fault analysis is to be carried out and serviced. The machine is brought into a safe state according to the instructions of the machine manufacturer and a backup of the machine control is created. Normally, machines in the production line exchange data with each other within the production network. The data from production is usually processed, analyzed and stored in the edge server.

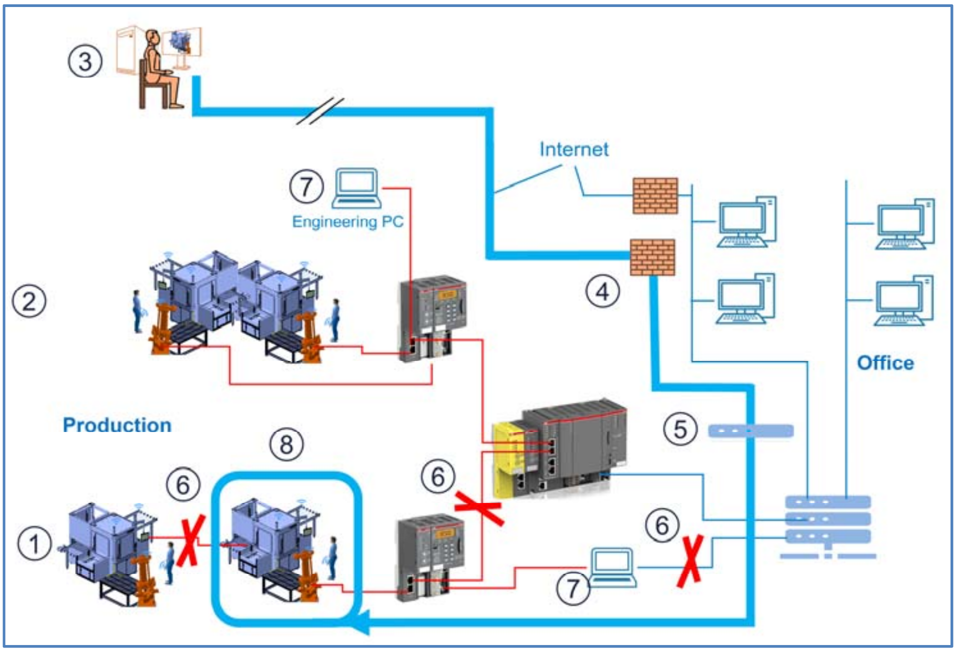

Figure 4. Remote maintenance on a machine in the production line 1,2- production lines, 3- remote maintenance specialist, 4- firewall, 5- hardware for remote maintenance, 6- disconnect connections before maintenance, 7- engineering PC, 8- machine to be serviced

Due to advanced digitalization, data from the production line is further forwarded to the administration and management in the office network. Before the remote maintenance specialist is connected to the machine, the machine to be maintained is disconnected from the other machines in the network and from the office network so that the remote maintenance specialist only has access to the specific machine. Access to the machine is granted for a certain time, after which the connection is automatically disconnected. Only the ports necessary for service remain open. The hardware components necessary for remote maintenance should not be used for other purposes. The connection to the remote maintenance specialist is always established by the operator IT department to the remote specialist. After authorization, the specialist's computer is scanned for malware and a connection to the engineering PC is established. The person responsible at the machine must first instruct the remote specialist, i.e., explain the problem area, show the machine status, introduce the persons on site and state their tasks. On the engineering PC, the communication with the remote maintenance specialist is monitored, recorded and saved after completion of the maintenance and archived with the operator.

5.2 Implementation of remote services on the injection moulding machine

Injection moulding machines for plastic parts are series products supplied by machine manufacturers to customers worldwide. Support for the operators of such machines via remote services are successfully established.
Before remote access is set up, a backup must be made of the user program and archived so that the previous status can be restored if necessary. An operating manual for remote maintenance is prepared and all persons involved are instructed according to the role within the remote maintenance team. The machine is brought to a ''safe mode'' and the upcoming remote access is discussed.
The remote access set up on an industrial machine is summarized in seven steps in an example in Fig. 5:

1. The operating instructions for the injection moulding machine describe the operating modes for remote maintenance. In particular, the preparation of the machine for remote access must be clearly explained.
2. The remote maintenance process is contractually agreed between the operator of the machine and the service provider/machine manufacturer. In particular, the duties and responsibilities of the respective contractual partners must be specified.
   Note: Remote maintenance is carried out in accordance with the legal regulations of the country in which the injection moulding machine is installed.
3. Before starting the remote maintenance, the operator puts the machine into the ''safe mode'' and prepares the machine according to the operating instructions or the agreement.
   An example of the safe condition of an injection moulding machine could be defined as follows
   - Machine is cold
   - Screw conveyor is empty, without pellets
   - Mould in ''open'' position
   - Safety doors are closed
   - Control is in manual mode

   All parts of the system that are not required for remote maintenance and are potentially dangerous are switched off, e.g., feed system, extraction system, cooling systems, etc. The control system is switched on in the operating mode for remote maintenance.

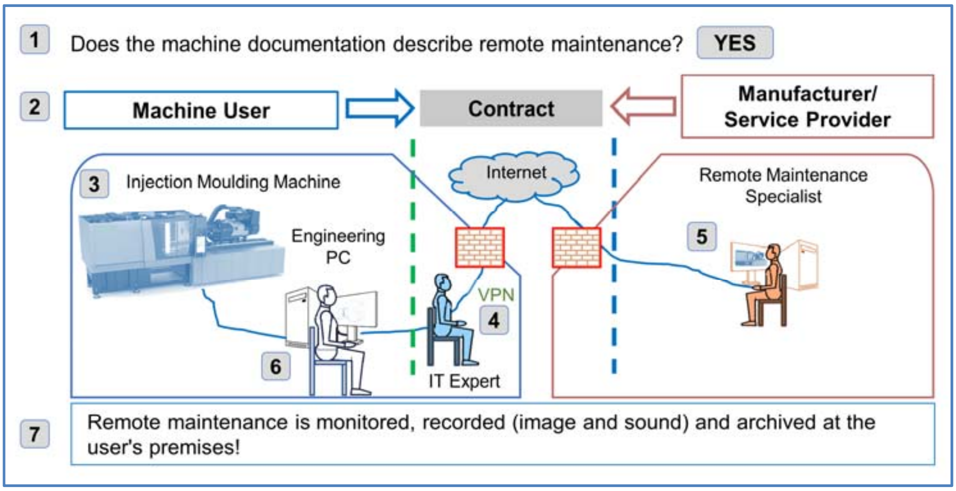

Figure 5.Implementing remote maintenance correctly in seven steps

4. The operating company's IT specialist prepares a VPN connection for remote maintenance and sends an access code to the remote maintenance specialist. The remote maintenance specialist's computer is scanned for viruses. After successful authentication, the VPN line is integrated into the IT network segment of the machine to be maintained, including the engineering PC, and communication is monitored.
5. After the connection to the control system has been established, the remote specialist is instructed by a safety specialist of the operator. Then the remote specialist first checks the safety status of the machine. After being prompted by the remote specialist, the operator performs the necessary steps.
6. During maintenance, an employee of the maintenance department observes and documents the work of the remote specialist via engineering PC.
7. After completion of the remote service, all records and documentation are archived at the operating company.

5. Conclusion

For remote maintenance, the machine manufacturer must provide the ''Remote Services'' mode in the machine control, therefore a risk assessment must be performed for all modes and described in the technical documentation. When the machine is commissioned, all operating modes are checked for their function and integrated into the company organization. Before starting remote maintenance, the machine must be set to ''safe mode'' and a backup of the software must be made. The connection from the machine to the remote maintenance specialist is established by the IT/OT department and the

communication is monitored. Work and cybersecurity measures must be followed. The agreed maintenance work is carried out by the remote maintenance specialist and the operating company documents the work. After the remote maintenance is completed, the documentation is archived.
Remote maintenance must be tested at regular intervals so that the hardware and software can be checked, the roles of the specialist personnel can be practiced and the process can be evaluated. Only when personnel are trained and practiced, all software is tuned, and networks are functioning, can remote maintenance be expected to be fast, efficient, and, most importantly, secure when needed.

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Cloud Manufacturing System for Collaborative Process Planning

Mijodrag Milosevic[*1]

Abstract: *The tendency of accelerated development of Cloud technologies enables the development of distributed application systems, which overcome traditional physical and time limitations, with the help of which geographically dislocated users, systems, resources and services are connected. The creation of an efficient, flexible collaborative environment in the field of designing manufacturing process plans is made possible by the use of Cloud technologies as well as advanced technologies from the business domain of modern manufacturing enterprises. This environment enables collaboration of project teams based on the exchange of digital information, thus ensuring greater innovation and better quality, while reducing costs and time needed to bring a new product to market. The paper will present one such Cloud manufacturing system intended for collaborative design of process plans in manufacturing.*

Keywords: *Industry 4.0,cloud manufacturing, process planning, collaborative engineering*

1. Introduction

Frequent product-related changes result in the emergence of multiple product variants, and distributed collaborative engineering brings new tools and methods for more efficient work administration during all phases of the product life cycle, for different product variants and customer needs [1]. Using CloudManufacturingSystem (CMS), designers, engineers and experts canexchange and share tasks and knowledge on a global level. In modern conditions, the production of complex products is realized in a large number of enterprises based on the principles of distributed production. Enterprises are specialized in partial process plans. Complex products, consisting of a large number of parts, components and modules, are assembled into a functional unit in one enterprise, but their parts are produced in different parts of the world [2]. Therefore, improved coordination is needed between teams collaborating from different places on the same manufacturing project. Design of Manufacturing Process Plans (MPP) is one of the very important tasks to be solved in a distributed production environment, in which different enterprises participate in collaborative product development [3].Activities related to the design of MPP

[*1] University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Novi Sad, Serbia, E-mail: mido@uns.ac.rs

are most often implemented at the intra-enterprise level using the CAPP system. In doing so, procedures are applied and executed that take engineering drawings, lists of materials and other technological specifications as input information in order to identify and select main processes, resources, sequences, operations and other parameters that are necessary to transform the raw material into a final product. CAPP tools integrate decision-making mechanisms and knowledge rules and build the basis for defining MPP, but their integration with other functions in the enterprise, such as financial flows, production planning, management of production resources, quality control, procurement, etc., is not simple at all. Nevertheless, this integration is necessary in enterprises that participate in a collaborative process with other enterprises in order to accelerate the development of new products, where the main motive is competitiveness on the global market. A network of enterprises participating in collaboration that includes both suppliers and end users can be defined as an extended enterprise [4]. The purpose of this integration is to achieve competitive advantage by maintaining distributed collaboration throughout the organizational structure. The functioning of the expanded enterprise is based on the use of the Internet technologies, because in this way the infrastructure is provided, by means of which information is simultaneously available to all participants in the planning of the production process, be it designers, experts, production managers, production workers, etc. Therefore, in Industry 4.0 concept, new paradigms are being introduced that combine Internet technologies and manufacturing, such as Cloud Manufacturing (CMfg) [5] and Industrial Internet of Things (IIoT) [6]. However, from the point of view of designing MPP, integration is often slowed down by various limitations. These are the most common limitations in the integration of CAD/CAPP/CAM systems, as well as limitations regarding information on technological capacities and resources, which are necessary for dislocated experts to design MPP.These problems can be solved using cloud-based, distributed, flexible, open systems for designing MPP in a collaborative environment. A system for collaborative process planning must help users to define MPP with the required level of detail. A common scenario of an expanded enterprise is the case when there is one enterprise, which uses the production services of another, geographically distant enterprise, in order to produce the necessary quantities of products while meeting the appropriate quality, costs and delivery time [4]. It is common for the observed production enterprise to require the design of its MPP in a collaborative environment, with the aim of taking into account the knowledge and experience of people from production, so that the MPP is efficient. In order to achieve this, it is necessary to identify all collaborative activities and flows of information and knowledge and integrate them into a collaborative cloud manufacturing environment that enables good engineering communication and coordination.

2. Development of the Cloud-Based Collaborative Environment

A CMS for collaborative design of MPP should ensure effective cooperation of all relevant subjects participating in the immediate preparation and planning of production. The basic task of this system is the effective inclusion of appropriate human resources in the decision-making process when defining the MPP of making a certain group of products. However, considering that decision-making cannot be realized without adequate input of geometric and technological data, as well as data on immediate production conditions and resources, the CMS should also provide access to key data on the basis of which appropriate technological solutions will be reached. In addition, the system should enable the archiving of obtained solutions, with the aim of their future analysis and exploitation, as well as the generation of appropriate documentation. Bearing in mind that such a system is applied in conditions of distributed production, the imperative should be the application of modern information and communication technologies, i.e., above all, the application of Cloud technologies. The development of a system for collaborative design implies a preliminary analysis of the collaborative environment in which the planned collaborative activities are implemented.

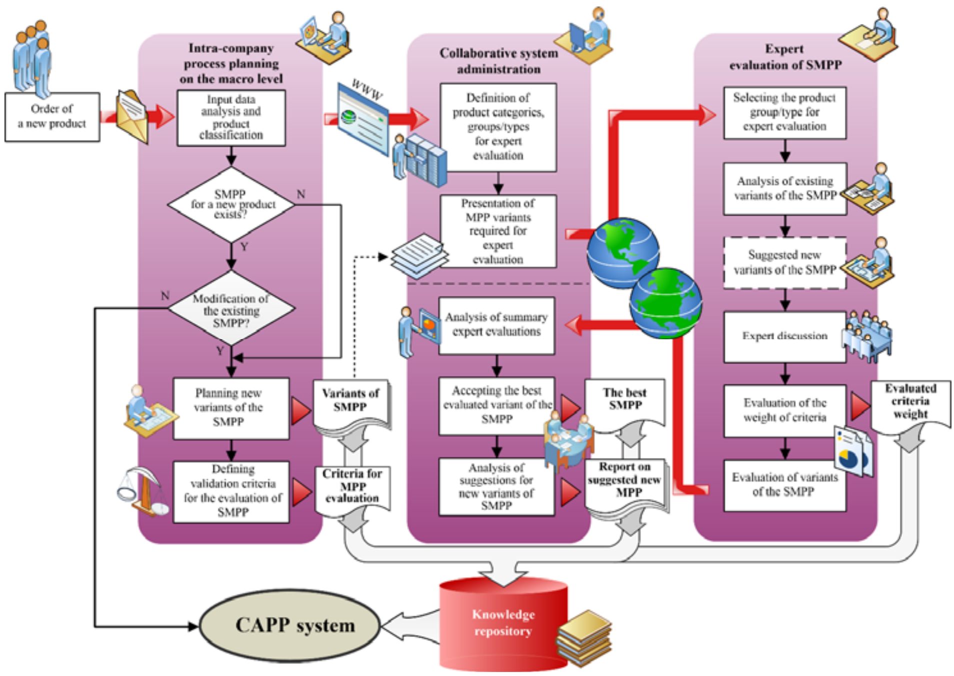

Figure 1.The collaborative environment for MPP [10,11]

One of the entities that initiates the collaborative process is an external enterprise that orders products from the parent enterprise that deals with production, but also with the preliminary design of MPP. The parent enterprise can function in conditions of distributed production, which implies physically separated elements of the production plant, that is, design departments. It goes without saying that this structure of the extended enterprise functions on the principles of e-Manufacturing[7], i.e., Cyber production [8] and that it is necessary to implement an appropriate collaborative system that enables immediate cooperation and quick transfer of necessary information between all segments of the enterprise [9]. The structure of the collaborative environment for MPP designing is shown in Figure 1. In this case, the CAPP system is partially based on a variant process planning technology that uses standard manufacturing process plans (SMPP).

2.1. Modelling of the engineering collaborative processes in the CMS

The presented collaborative environment includes a large number of subjects and factors that base their functioning on the application of the Internet and Cloud technologies [12]. Experts involved in the collaborative process must have access to all necessary data, regardless of their geographic location. Therefore, the CMS should be developed in such a way as to satisfy all the requirements of remote experts and engineers, but at the same time to enable efficient implementation and application within the parent enterprise. One of the basic tasks of the CMS is the collection of expert heuristic knowledge in order to expand the knowledge base for the automated design of MPP. In addition, the system must be reliable and provide adequate protection of data belonging to the parent or extended enterprise.

Bearing in mind the mentioned requirements, one of the primary stages in the development of the system is the observation of key actors in the collaborative environment, as well as their roles, that is, the tasks they perform in the collaborative process. Modeling and visualization of basic entities and processes in the system will be performed using UML, as a standard modeling language.

UML includes information about the static structure and dynamic behavior of the system. A system is modeled as a collection of discrete interacting objects. Static structures define the types of objects important to the system and its implementation, as well as the relationships between objects. Dynamic behavior defines the history of objects in time and the communication between objects to achieve certain goals. Representing the behavior of the system from different perspectives that are interconnected allows a better understanding of the system.

UML allows the construction of diagrams that model the system by describing:

- Conceptual elements (processes, system functions, etc.) and
- Deployment elements (program components, data schemes, etc.).

In addition, UML is used at many different levels and in many stages of the development cycle. The basic diagrams provided by UML, which will be used here in the development of the CMS, are:

- Use case diagrams,
- Sequential diagrams,
- Activity diagram and
- Collaborative diagram.

The use case is a technique used to describe the possibilities of the planned system from the aspect of interaction between the system and the user. Use case diagrams are a way of presenting the functional requirements of a system and describe what the system does, not how. The main objectives of these diagrams are related to:

- Communication between the user and the development team,
- Deciding and describing the functional requirements of the system,
- A consistent description of what the system should do,
- System verification and
- Testing the system and checking the intended functionality.

Figure 2 shows a diagram of the use case of the CMS for the design of MPP, where the main actors, their basic roles and expected interactions in the system are presented. Four types of actors are foreseen in the system: product orderer, engineers, experts and system administrator. Each of these actors has intended roles within the CMS that interact with each other and can be shared and/or extended by other use cases. A detailed analysis of interactions over time between objects is shown by an interaction diagram. UML interaction diagrams show how objects in the system communicate with each other [13]. They show flows through use cases step by step, where you can see which objects are necessary to execute the flow, which actor initiates the flow, which messages are exchanged between objects, and what is the order of sending messages. One of the interaction diagrams is a sequential diagram that shows different processes or objects in the system that exist at the same time, as well as their interactions and the messages exchange with each other. In this way, the graphical display of user scenarios, i.e., objects, life lines, interactions and messages in the system is enabled.

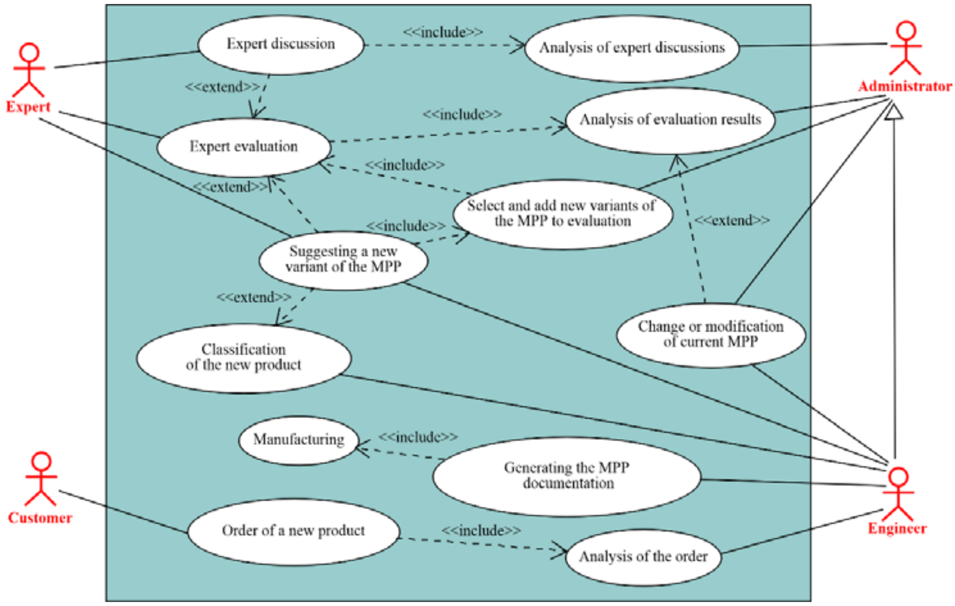

Figure 2.The main use case diagram for the CMS

UML interaction diagrams show how objects in a system interact with each other. They show flows through use cases step by step, where you can see which objects are necessary to execute the flow, which actor initiates the flow, which messages are exchanged between objects, and what is the order of sending messages. One of the interaction diagrams is a sequential diagram that shows different processes or objects that exist at the same time, as well as their mutual temporal interactions and the messages they exchange with each other. In this way, the graphical display of simple user scenarios is enabled. The elements of a sequence diagram are objects, life lines and symbols of interactions and messages.

Figure 3 displays a sequential diagram of collaborative design shown in accordance with the intended use case diagram. The process begins with the ordering of a new product by the customer, after which the technologist analyzes the order and creates variants of typical technological solutions. It is important to note that the collaborative design process can begin even without ordering a new product, if the development of a new product is one of the strategic goals of the parent enterprise or if there is a need to modify existing technological solutions. After that, the administrator selects the proposed solutions and enables their display in the web collaborative environment. Variants of technological solutions are available through the Internet to experts who are registered in the system, where they can propose new variants of MPP, discuss with each other and finally perform an expert evaluation. Expert evaluation consists not only of evaluation of criteria for evaluation of technological solutions, but also evaluation of the importance of individual criteria. The results of expert activities are available via the web to the administrator who analyzes them and generates reports. Engineers, i.e., experts within the enterprise, analyze these reports and make a decision on the choice of the current MPP that will be applied in the future for all products belonging to the observed group.

Team members can propose new variants of MPP, discuss and finally perform an expert evaluation. The parent enterprise analyzes the evaluation results and makes a decision on the selection of the best rated SMPP for the families of parts that will be implemented in the intra-enterprise CAPP system and applied in production in the future.

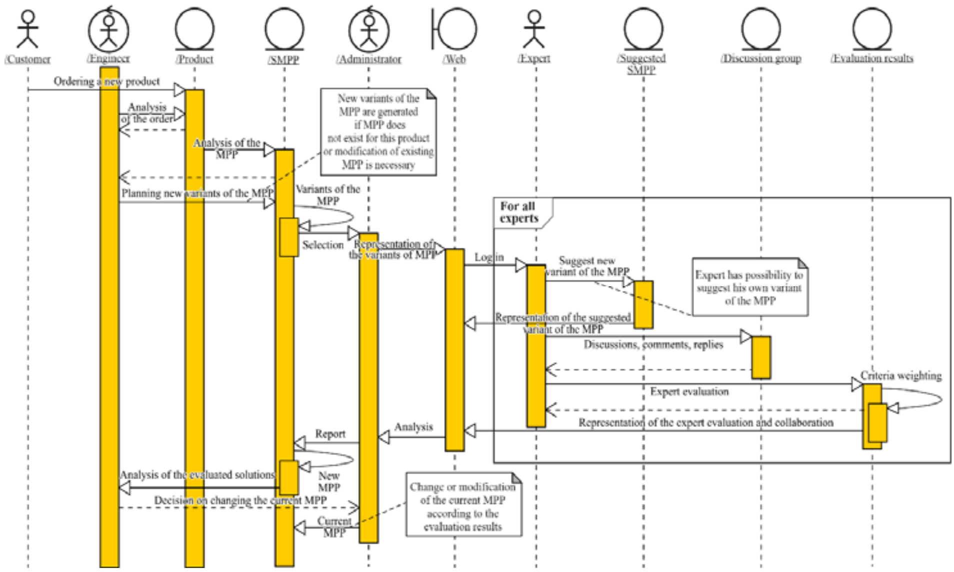

Figure 3.Sequential diagram of collaborative design of MPP

The role of the administrator in the CMS refersto the synchronization of the activities of the collaborative process, as shown in Figure 4. After logging into the CMS, the administrator can add new categories, types and groups of products, as well as variants of MPP that are intended for evaluation.

After the expert evaluation, the administrator analyzes the expert discussions and evaluation results and proposals for new SMPP. The evaluation can be monitored individually for each expert, or by analyzing the evaluations of all experts at the level of the observed product. The arithmetic mean method or the median method can be used to arrive at the best rated variant of a SMPP. On the basis of the performed analysis, a report is generated that will further serve the purpose of making a decision in the parent enterprise for possible changes to the existing MPP. In real manufacturing process, those solutions that are best evaluated or proposed by the experts, will be applied.

The sequence diagram shows the time-distributed administrator interactions within the CMS, as shown in Figure 5. The administrator logs into the system and adds new products, i.e., their variants of technological solutions intended for evaluation. Administration then refers to the analysis of expert profiles, discussions and results of expert evaluations. The proposed new technological solutions equally enter the variants of MPP for a certain type of product. Expert profiles can be deactivated by the administrator, so that their ratings are not included in the final summary analysis and do not affect the outcome of the assessment of technological solutions.

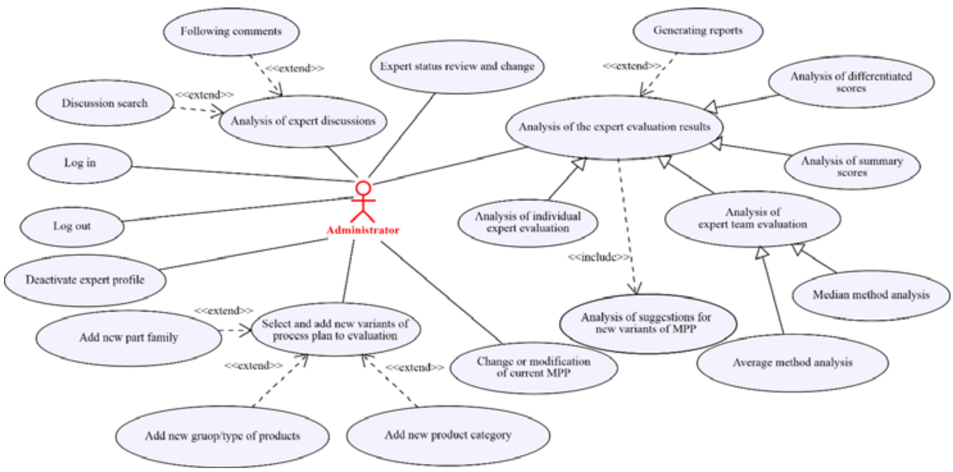

Figure 4. An administrator role in the CMS represented by a use case diagram

After analyzing the generated report, the administrator is enabled to change the current variant of the SMPP in the database, that is, the knowledge repository. From that moment on, for all new products that are determined by classification to belong to this type, the CAPP system will generate the MPP that was best evaluated by the experts.

The activity diagram represents a model of the dynamic behavior of the system. It describes the dynamics of the set of objects and the flow of the corresponding operations. In addition, the activity diagram describes logical procedures, business processes and business flows in the system. Figure 6 shows a diagram of the activities of the CMS, which consists of the corresponding activities and nodes where decision-making, branching or merging are performed. The diagram also shows the division of responsibility for each activity among three main executors: engineers, administrators and experts in three partitions or paths (swimlanes). The activities are arranged by paths, but there is a transition from one path to another.

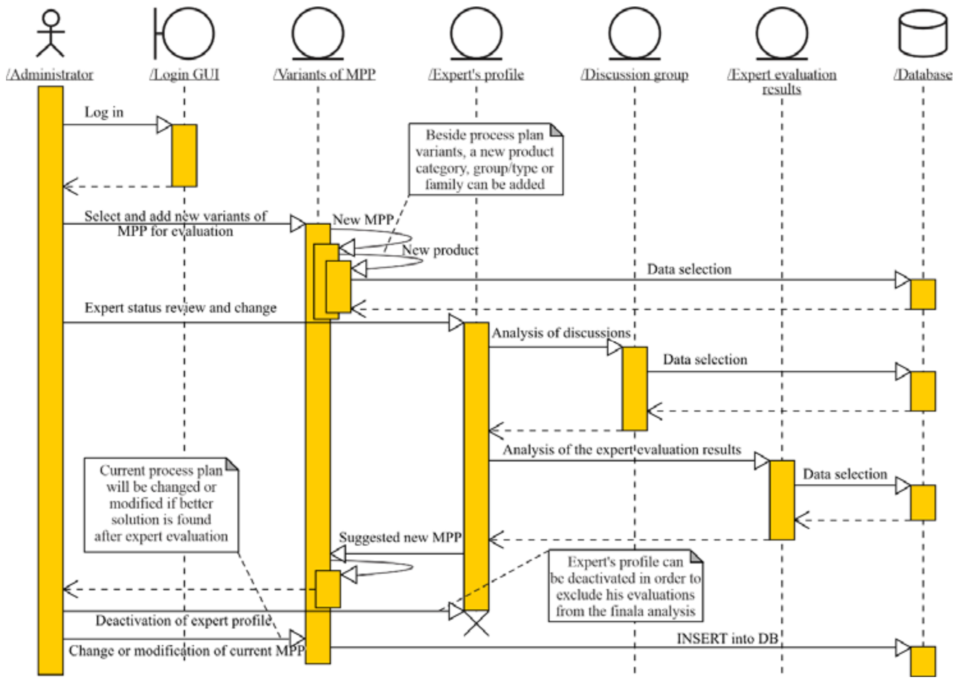

Figure5. Sequential diagram of administrator interactions in theCMS

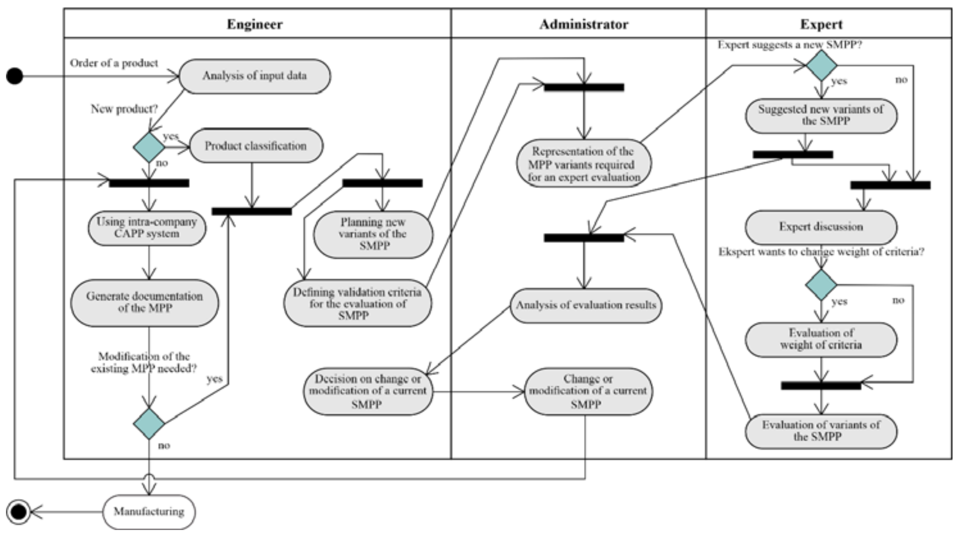

Figure 6. Activity diagram of the CMS

The diagram indicates that the engineer is responsible for the analysis of input data, product classification, the application of the CAPP system, as well as the design of new variants of SMPP. In addition, the engineer determines the criteria according to which the experts should evaluate the MPP and makes the final decision on the eventual change of the current SMPP after the expert evaluation. On the other hand, the administrator mediates between engineers and experts by analyzing their activities and makes the necessary changes in the CMS. The expert makes possible proposals for new variants of technological solutions, participates in the discussion, corrects the importance of the evaluation criteria and, finally, evaluates the proposed variants of SMPP.

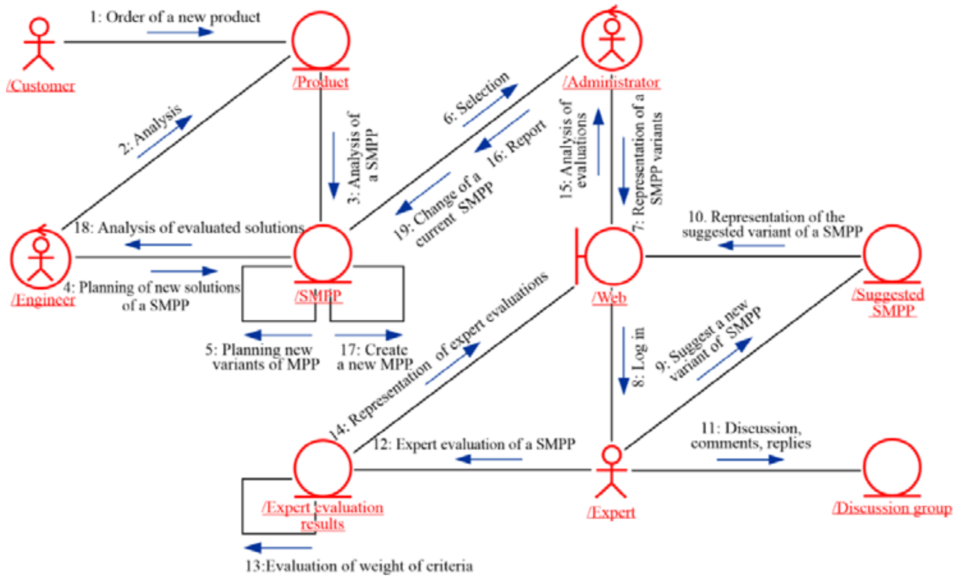

Figure7.Collaborative diagram of the CMS

Based on the presented sequential diagrams and activity diagrams, a corresponding CMS collaborative diagram can be defined, as shown in Figure 7. The collaborative diagram focuses on the interactions between objects in the system and defines their mutual relationships. The goal is to show the collaborative structure and organization of objects, that is, to show the messages that are exchanged between objects in the system.

By monitoring the order and direction of messages exchanged in the system, the flow of the collaborative process can be determined. The collaboration begins with the order of a new product by the external customer of the product, through the creation of variants of technological solutions and their expertise to the final analysis of the evaluated technological solutions and the modification of the current variant of the SMPP.

2.2. Model of the Cloud Manufacturing System

The core of this system is located within the parent enterprise A, whose primary task is related to the design of MPPfor products delivered by external enterprises B, C, etc. The parent enterprise bases its work on distributed design and production and may own enterprise A, in whose production plant direct production is carried out. In addition, bearing in mind the concept of modern distributed production, i.e., e-Manufacturing, it is envisaged that the parent enterprise will be integrated into a distributed network of enterprises, organizational units and experts participating in collaboration and using the Internet as an effective communication infrastructure. Therefore, it can be said that the planned CMS functions within the framework of the extended enterprise.

It is envisaged that the parent enterprise will use a specialized CAPP system designed to automate the design of technological solutions oriented to its own production program. In addition, it is understood that the parent enterprise, i.e., the extended enterprise, operates on the principles of competitive engineering, whereby different CAx systems are used simultaneously in the development and analysis of the phases of the product life cycle. The established model and the planned program solution of the CMS will enable the design of MPP both for the given technological equipment of the parent enterprise and for the technological equipment chosen by the experts, as participants in the collaborative process.

The CMSconceptual model includes two basic groups of experts who participate in the collaboration process:

- Engineers and experts belonging to the parent enterprise and
- Dislocated engineers and experts who are in the organizational structure of the extendedenterprise.

Engineers and experts within the parent enterprise participate in production planning based on the needs of external enterprises, in proposing new technological solutions, as well as in interaction with CAPP and other CAx systems used in design and analysis, as shown in Figure 8. On the other hand, dislocated engineers and experts participate in evaluating proposed solutions, but also in improving existing ones and proposing new, in their opinion, better technological manufacturing processes. The knowledge of all actors in the collaboration is collected and organized in a knowledge repository that is available not only to production but also to organizational structures, i.e., enterprise management. The acquired knowledge will also be used in the application phase of the specialized CAPP system during the automated design of technological solutions for future new products.

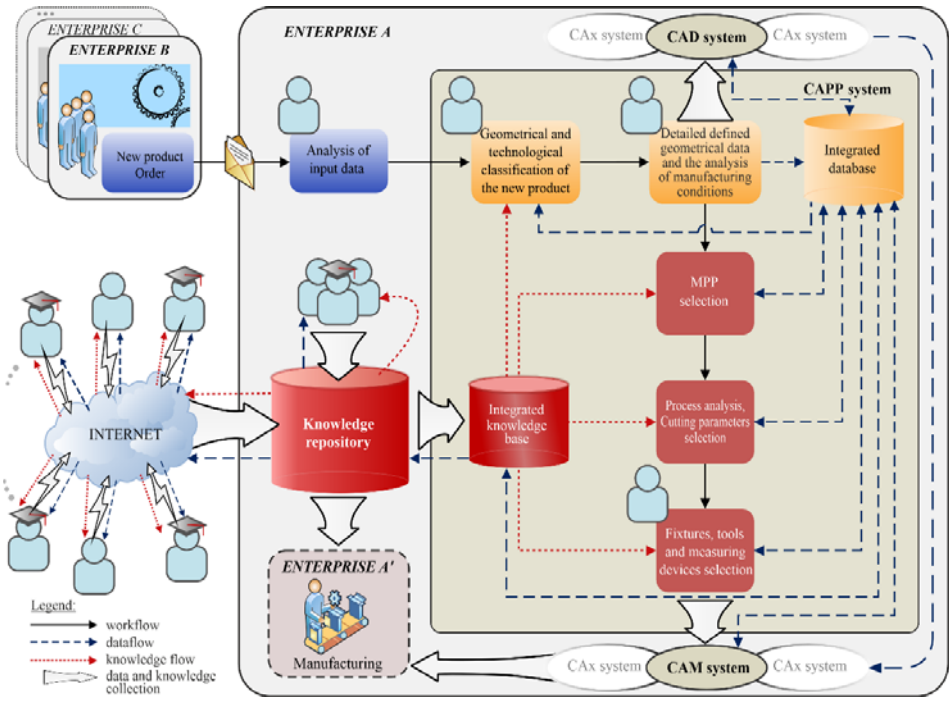

Figure8. Model of the CMS for manufacturing process planning

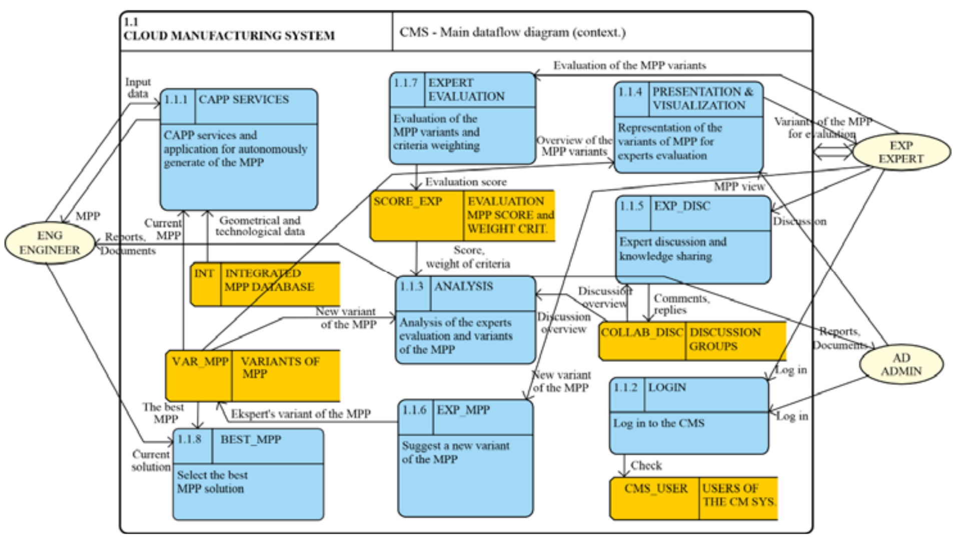

Figure9. Main data-flow diagram of the CMS

The information infrastructure in a CMS includes various flows of information and knowledge, as well as procedures for gathering engineering and expert knowledge, as shown in Figure 9. It is clear that the development of the model structure requires the application of a modern system for managing, organizing and distributing data. In addition to the need for dynamic manipulation of complex information structures, the database system must also enable adequate protection of information that represents a business secret at the level of the extended enterprise.

3. CMS Architecture and Verification

Figure 10 shows the global three-tier architecture of the CMS for designing MPP. The architecture, in addition to clients, i.e., experts, includes a collaborative server as well as a database server.

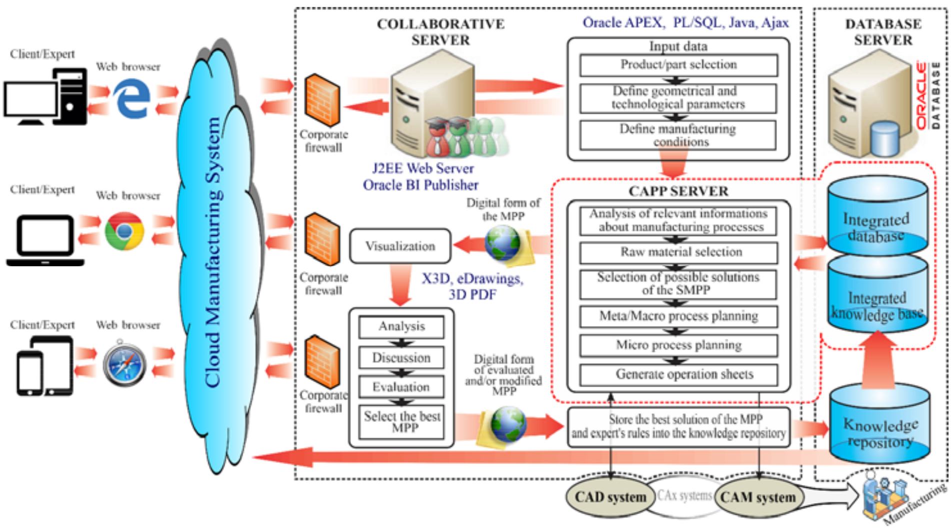

Figure10.Three-tier CMS architecture

The collaborative server has the function of enabling users, primarily experts, to see appropriate technological solutions, and also to enable the processing and storage of expert knowledge. The collaborative server accepts user requests and forwards them to the database server. These requests may refer to the display or writing of the corresponding data organized in the repository. Using the CAPP server, the automated generation of MPP of product creation is carried out on the basis of adequate input data. The functions of the CAPP server are based on procedures within the integrated knowledge base, whereby data on the macro design of MPP are downloaded from the knowledge repository. In this way, it is possible for expert evaluations to directly influence the technological solutions generated in the CAPP server.

The CMS provides expert analysis, discussion and evaluation in order to find the best solution of the SMPP for the given conditions. Experts are not conditioned by owning any commercial system for designing and interacting with a collaborative environment.

Figure 11. Verification of the CMS implementation

In the practical application of the presented CMS, it was performed on parts of the piston-cylinder assembly of the IC engine, which includes MPP for production of the cylinder liners, ribbed cylinders and pistons, as shown in Figure 11. The corresponding families of parts that are produced within the real parent enterprise were previously defined in the preparation phase of the CMS.

4. Conclusion

The development of internet technologies enables designers to effectively communicate, collaborate, share and exchange various resources during the design process. Cloud-based design environments represent a new paradigm in modern product development. Such environments are often used in all segments of product life cycle management, since all product and process data can be represented in digital form. Given that the design of manufacturing process plans represents a very important phase in product development and production preparation, most of the presented research is focused in that direction.

In the paper, first of all, the importance of the application of Cloud technologies in the design of manufacturing process plans and modern preparation of production was observed. Thanks to new tendencies in the development of Cloud technologies, engineers and experts are enabled to create effective virtual design environments that function on a global level.The CMS enables dislocated development teams and experts from the field of MPP design to collaborate and exchange knowledge. In a collaborative process, experts can evaluate existing technological solutions, modify them or propose completely new MPP. In addition, the system enables the collection of expert heuristic knowledge into the appropriate knowledge repository at the level of the extended enterprise.

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Industry I4.0, Education E4.0, Web 4.0 and Knowledge Needs

Darko Lovrec[*1]

Abstract: *Industry I4.0 is a term we always come across when talking about today's advanced technologies, especially in manufacturing plants. At the same time, we usually forget that the latest development, stage I4.0, was achieved mutually through the acquisition of the necessary knowledge, which was becoming more and more diverse, and had to be obtained in an ever-shorter time. From the point of view of education, similarly to industrial development, we can also talk about today's level of education, i.e., Education E4.0. An important contribution in the development of technology, both in terms of I4.0 and E4.0, undoubtedly enabled the development of web technologies. Web technologies also developed gradually, but much more intensively and in a shorter time, until the current state of Web4.0.*

The paper summarizes, in a transparent manner, the characteristics of the individual development stages of the state of the industry from I1.0 to I4.0, education from E1.0 to E4.0as well as the impact of web technologies from Web1.0 to Web4.0. At the forefront of the discussion is the interactive influence and development of all three mentioned key players, which, mutually, have led to the current state, which could be called Technology Society 4.0. In this case, the individual necessary knowledge, skills, as well as the methods of imparting and acquiring knowledge, are given according to individual development periods.

Keywords: *Industry I4,0, Education E4.0, Web4.0, milestones, interaction, knowledge*

1. Introduction

Industry I4.0 is an extremely common term these days denoting the current state of technology and ''spirit'' connected to every pore of our daily life. The fourth industrial revolution, Industry I4.0, emerged with the introduction and use of control over various production processes, using data-driven scientific methods and intelligent production structures. Ever since the first industrial revolution, our view of the world has been changing constantly, and for each period the view is different, aligned with the state of technology and the necessary knowledge and skills. Thus, considering the turning events and related time milestones, today we can talk about the development stages of industrial development, from the initial Industry I1.0 to the current Industry I4.0.

[*1]University of Maribor, Faculty of mechanical engineering, SI 2000 Maribor, Slovenia
E-mail: darko.lovrec@um.si

Similarly, we can discuss educational revolutions (or evolutions) in terms of the necessary learning content, knowledge and skills in education. These are also time-defined in some way, according to the method of implementation and approach to the states from Education E1.0 to Education E4.0 (or also referred to as Classroom C1.0 to Classroom C4.0), except that these stages of educational development are less known to the general public.

The latest, modern approaches to education have certainly been made possible by the extremely fast development of the Internet and web technologies. From this point of view, the development stages could also be divided into time periods from Web1.0 to Web4.0. Unlike the development phases of education or the development stages of industry, the development of web technologies took place extremely quickly and in a much shorter period.

For a better understanding of the temporal correlation, mutual content connection and mutual influence between the individual stages of the development of industry, education, and the development of the World Wide Web, we will first summarize the basic characteristics of all three, that is I, E and Web development stages briefly.

2. Industry Development Stages from I1.0 to I4.0 – Necessary Knowledge and Skills

The period of *Industry I1.0* (beginning around 1760) was characterized by using water and steam-powered hardware and a suitable way of transferring the motive power to individual workplaces. This period was characterized by use of transmission of mechanical energy transfers and the arrangement of machines according to the available power.
Before the invention of the steam engine the sequence of (manual) machining and production processes was managed (and determined) by one person. During the period of manufactory, the benefits of the division of work were used. The first work groups that performed only one operation appeared and the flow of material was organized and regulated. The situation changed when an independent source of energy appeared in the form of a steam engine. From the central power supply, the transmission of power to mechanized processing devices was carried out via transmission drives. The flow of energy was dominant, determining the layout of the machines, and, thus, the design and appearance, as well as the dimensions of the factory. The arrangement of the machines was carried out according to their type or type of processing (e. g. turning, milling), or according to their size (large, small machines).

The necessary knowledge and skills in this period could be said to have required knowledge in the field of energy production (mainly steam), the construction of machines operating on this energy, knowledge of energy transmission and transmitters, and knowledge of basic manufacturing technologies.

The next era, *Industry 2.0* (beginning around 1870), was based on the division of labour and mass production using electricity. In the second half of the 19th century, the discovery of the electrodynamic principle by Werner Siemens led to the use of the electric drive as an alternative source of power. In the following years, this replaced the central energy supply. The first independent, autonomous drives appeared on transfer lines at Ford (1912), and in Europe in the 1920s. The predominance of the flow of energy was replaced by the predominance of the flow of material or of the product. The Second Industrial Revolution was a period of great economic growth, with increased productivity and the replacement of workers using machines.

Based on the required knowledge, there was a need for additional knowledge related to the structure, properties and possibilities of using electric drives and electricity transmission. In addition, due to higher production speeds, there was a need for knowledge about new cutting tools and materials, as well as knowledge in the field of production organization – assembly lines and mass production.

Industry 3.0, also known as the digital revolution, began around the 1970s, with the partial automation of machinery and equipment using microprocessor programmable controllers and computers. It was based on the use of electronic and information technologies for further automation of production.
This era was characterized by the mass production and widespread use of semiconductor digital logic, MOS transistors and integrated circuit chips, and technologies derived from them, including computers, microprocessors, digital mobile phones, and even the Internet. These technological innovations have changed traditional production and business methods. In essence, we can say that the digital revolution has changed technology, from analogue to digital – the era of digitization.

During this period, there was a need to master completely new skills, not only analogue electrical engineering, but also digital engineering. Extraordinary progress in the field of electronics dictated a whole range of special skills and related learning content in the field of electrical engineering and automation, which had to work in symbiosis with various drive concepts (mechanics, hydraulics, pneumatics). This led to a new look at the machine or device, to new, advanced conceptual solutions – Mechatronics.

Industry 4.0 (today's characteristic state) is based on the use of cyber-physical systems where the real world is connected to the virtual (and vice versa). Industry 4.0 is somehow the gateway to the modern world, which includes Cybernetics, Robotics, Big Data, Nanotechnology, Artificial Intelligence, Automation, global citizenship, the digital age, and many other concepts in our lives. (e.g. [1], [2], [3])

In any case, this period has a radical impact not only on the set of necessary modern knowledge and learning skills, but also on the ways of imparting knowledge. The recent Covid-19 pandemic has additionally contributed to the use of new, innovative approaches to acquiring knowledge.

Figure 1 shows a timeline of the mentioned industrial revolutions with their basic characteristics.

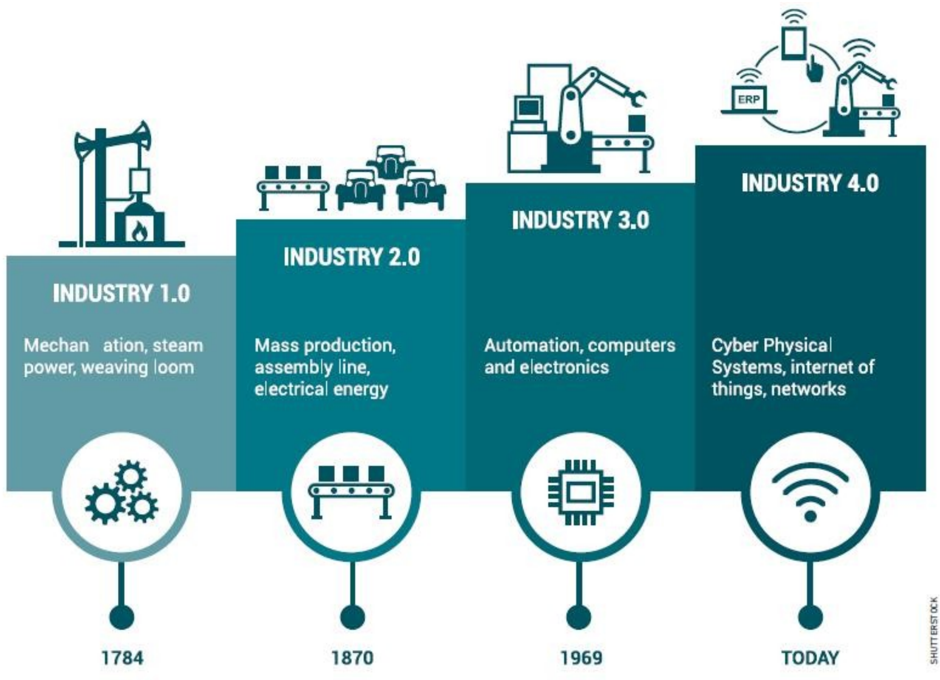

Figure 1. Industrial revolutions through time – from I1.0 to I4.0 [1]

It is absolutely necessary to know the characteristics of the development period of technology, as educational content and the process of imparting knowledge are closely related to them. Users and designers of machines and devices must have knowledge of what industry needs in a certain period.

3. Education Development Stages from E1.0 to E4.0 and Pedagogical Approach

Similar to the development stages of industry and technologies, the methods of education can also be divided into characteristic stages of development, both in terms of time and content as well as in terms of implementation and approach.

Rapid technological development, especially in the last fifty years, has not only influenced changes in the industrial field, but also in education. Similar to the given milestones and stages of industrial development Jacke Gerstein [4]has written down the tentative and approaches in the field of Education, Development Stages of Education, as Education E1.0, E2.0 and E3.0. Nowadays, due to new possibilities and major changes in this field, we have moved to a new, higher level of educational approaches. We also added the stage Education E4.0. The current state E4.0 has been influenced greatly by the development of the Internet and web technologies.

The beginnings of the individual phases of educational development, E1.0 to E4.0, did not coincide in time with the initial periods of the industrial revolutions from I1.0 to I4.0, and they did not last for the same length of time either. All major changes in the way knowledge are delivered have occurred in the last 50 years (before that there were no major, noteworthy changes). By comparison, changes in industry took place over a much longer period of about 250 years. Therefore, there is more divergence regarding the milestones of the development of education than with the milestones of industrial revolutions, where these milestones are defined much more clearly, as they are based on major discoveries and the implementation of achievements in the industry that they changed drastically.

According to some reports, the milestones of (modern) education have been shifted to the present time, as they are limited to the use of the Internet and modern ways of imparting/assimilating knowledge (e.g. [5]), while other sources cover a much wider period (e.g. [6]). Considering the longer time distribution of the levels of educational ''revolutions'', we can list the most important characteristics of each level from E1.0 to today's E4.0. The focus here is on providing knowledge at higher education institutions.

Education E1.0 is the manner and method of imparting instructions during the ancient and Middle Ages. The process of teaching within that time was personalized and in close contact with the teacher. *This ancient way of education was limited to only a few students, usually selected from the elite class, and it was an informal education and not a structured curriculum. The teacher* *sharedhis knowledge with the students according to his choice, depending on his will and desire, and his mood and current inspiration*. This informal education system existed in India, where the teacher was called a guru, and the method of imparting knowledge was the Guru-Shishya Parampara' method, similar to Teacher-Student relationship. Apart from India, such a way of imparting knowledge was also typical of China, Israel, Rome and Greece, and also in tribal societies (this is still the case in some places today).

Although there was no formal curriculum at this time, E1.0 education changed gradually from basic non-formal education to the beginning of higher education, resulting in the establishment of a few universities, such as Nalanda, Takshashila, Ujjain, Viramshila in India and Heian-Kyo in Japan in the 9th century. Religious and spiritual education were also important during this time.

Education E2.0 emerged when, *during the mid-15th century, the invention of the printing press changed the dynamics of knowledge reproduction & sharing the system of knowledge. During this time, books became crucial to the spread of knowledge. In the era of Higher Education 2.0, the process of knowledge transfer changed, and the one-to-one concept (from teacher to student) became one-to-many (from teacher to several students in a class).*

During this period there was only a partial revolution in the pedagogical process, renaissance, reforms and the establishment of universities as centers of higher education. Between the 14th and 18thcenturies, universities were already established in Europe and many other countries, which also opened the door to higher education to common people. *It was a path from the education only of individuals who belonged to the elite to the mass education, including the education of women. Informal education became formal and individual disciplines appeared, so-called subject-oriented knowledge.*

The period *Education E3.0* can also be called the period of democratization of all levels of education, including higher education, which increased the accessibility of all levels of education greatly. *In this state, the state of the 20th century, the blackboard has been replaced using Information and Communication Technology (ICT),* which is often referred to as boring ICT education, in other words: just showing slides, ''slide-show'', ''sliding''. This was the beginning of the digital age, which consists of technology, the use of computers, improved administration and (assumed) better learning, research and development in all disciplines dominated by science and technology.

ICT can have a compelling impact on student learning or the appropriate acquisition of knowledge only if teachers are also digitally ''literate'' and understand how to integrate these approaches into the curriculum. Different schools in different settings use a diverse range of ICT tools to communicate, create, disseminate, store and manage information. The ICT method also includes education through radio and television broadcasts as well as information already available on the Internet.

The further development of ICT, especially in the field of higher education, has led to a higher level than E3.0 (which is still level used extremely frequently today), i.e., to the *new era Education E4.0. The E4.0 education approach puts the learner at the center, and enables him/her to choose the method of education by structuring an individual path to achieve individual goals* (the latter applies mainly to higher education). It is the so-called collaborative and personalized learning. Now, learners can acquire knowledge at school, on campus, at home, and even at work, every day of the year, depending on their available time, moods and willingness to learn.

Figure 2 shows a timeline of the mentioned education revolutions with their basic characteristics.

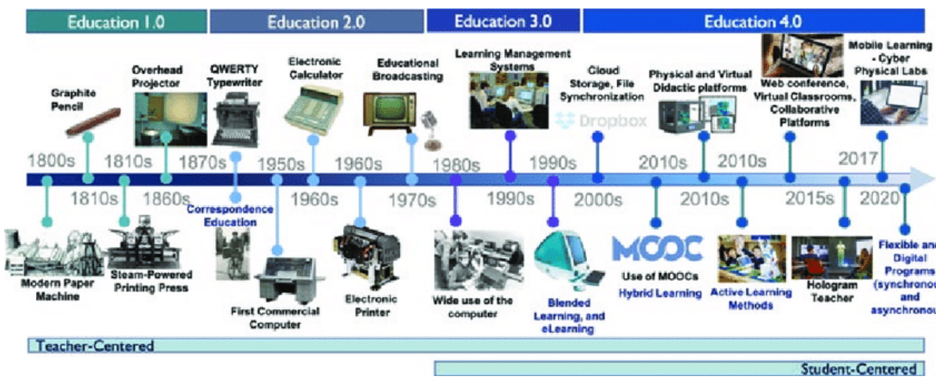

Figure 2. Evolution of technologies and learning methods according to the four periods of education, leading to the Education 4.0-Timeline [6]

Education 4.0 is based on the availability of content. Everything the learner needs is available when he needs it. For this, it is necessary to have a ready-made collection of educational materials that can be offered to learners, especially for students. In this way, they can cover all their needs, whatever they may be. The correct fragmentation of the various learning subjects is essential, as, in this way, we can give the system a certain dynamic, which can be adapted to the student's needs at any time. Learning is not focused strictly on just one specific goal, but is also personalized. It can be integrated easily with other materials and students or needs for new skills. The latter is especially important after completing formal education, when the need for new knowledge and skills is dictated by the new work environment. Such an approach is typical of the upcoming method of obtaining appropriate Micro-Credentials for a specific professional area and learning content (shorter, topic-oriented learning content with a flexible way of acquiring knowledge, checking it and with the possibility of upgrading). These development facts, development directions and goals are also recognized by the OECD, and guidelines for educational approaches in the future are provided in its documents. [7]

Such an approach enables different ways of cooperation and models of independent learning, where the teacher is more in the role of a mentor (as a provider of knowledge), who (more or less actively), monitors the student's acquisition of knowledge. This is not just about uploading some videos to Youtube and some pdfs, as this approach may be misunderstood, and which we were forced to introduce in the initial period of the Covid-19 pandemic, where the new approach and availability of content for remote learning was indeed ''necessary set up overnight''. It actually means creating a *dynamic learning system* that is in constant interaction with the learner and changes the content offered according to their specific needs at a given time. This is done by including the learner in a heterogeneous group of learners where, although each has their own specific and special needs, they converge at certain points to complete common tasks. [8], [9]

4. Web Development Stages from Web1.0 to Web4.0

The latest state of education, Education E4.0, was made possible by the development of Internet and Web technologies. If, in terms of time, the development of industry from I1.0 to I4.0 took place over about 250 years, major changes in the education system from E1.0 to E4.0 took place in a five times shorter period, i.e., in the last fifty years. Internet and Web technologies, from the first beginnings of Web1.0 to the current state of Web4.0, have developed in ten times less time than the development of the industry from I1.0 to I4.0 in the last 25 years. The latest Web4.0 technologies enable all the advantages that characterize both E4.0 and I4.0. Internet technologies definitely belong to the field of new, modern technologies, which have not only enabled certain improvements in all areas of technology and life, but also enabled completely new solutions.

The Web is the largest transformable-information construct, and its idea was first introduced by Tim Burners-Lee in 1989. [10], [11] Much progress has been made about the Web and related technologies in the past two decades. Web1.0 is

a web of cognition, Web2.0 is a web of communication, Web3.0 is a web of cooperation and Web4.0 is a web of integration. [12] Let's take a brief look at the basic characteristics of each degree which influenced the development of industry and education.
Figure 3 shows the development stages from Web1.0 to Web4.0 with the basic characteristics and differences. [13], [14]

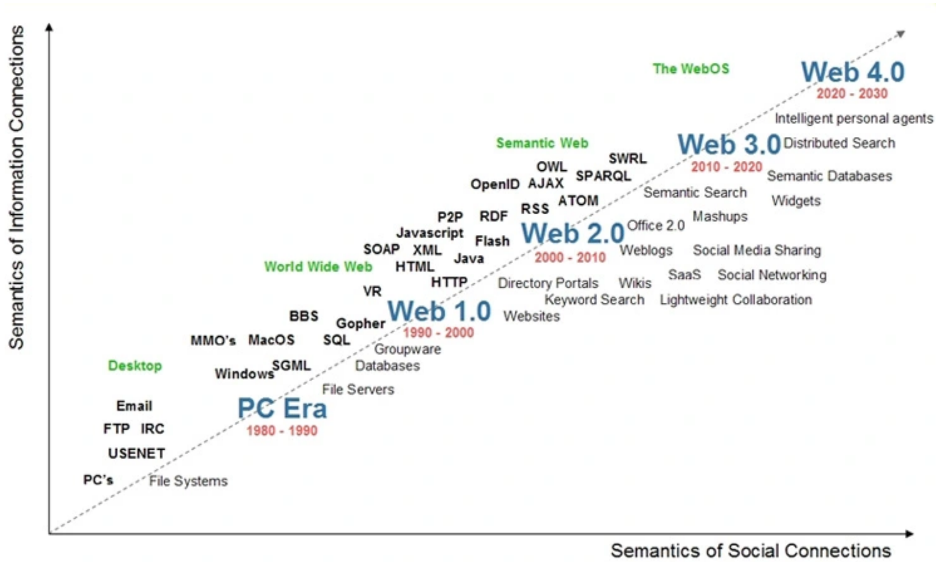

Figure 3. Development stages from Web1.0 to Web4.0 [14]

Web1.0, the first version of the World Wide Web, was developed by Tim Berners-Lee in 1989, and lasted until around 2004/2005. The websites of this era were purely informational in nature, and included only static, read-only content. There were no interactive content or design options, and the links were via hyperlinks. The primary goal of the first websites was to allow everyone to access public information and establish an online presence. Other than that, it was only possible to write and send text emails, while unable to upload or attach images. However, static pages hosted on web servers (managed by ISPS or free web hosting providers) were mostly personal websites. They were very popular and paid for. Websites were often designed by individuals or small groups of people.

*Web2.0,*with the advent of social networks and a simpler way of communicating from different parts of the world, ''opened up a new, wide world of possibilities'' to many people who, until then, worked in a narrow environment, in a classical and conventional society. Web2.0 appeared in the early 2000s, and, with the introduction of new technologies, marked the way of using the Web. Blogs, wikis and social media platforms appeared, such as Facebook, Twitter, YouTube or Discord. Thus, users could communicate with each other and with online content in new ways (creating their own content and sharing it with others).With Web2.0 there was a shift from static, read-only content to dynamic, interactive content. Web 2.0 is seen as a people-centered, participatory, read-write web designed for two-way communication. Unlike Web1.0, Web2.0 gives more control to users and provides interaction, bringing about major social changes. All this has led to the spread of the Internet, and also to various mobile devices such as iPhone and Android, leading to the dominance of applications such as WhatsApp, Instagram and others, up to e-shops and the collection and analysis of customer habits.

Web3.0 is a new type of web, that emerged around 2006 and has been defined as the intelligent or semantic web, that includes integration, automation, discovery and data, thus promoting mobility and globalization. Powered by Artificial Intelligence (AI) it makes it easier for users to search, share and combine. It allows a person or computer to start in one database and then move through an infinite number of extensive databases – Big Data. The goal of linked data is to enable computers to do more useful work for us by teaching machines how to read web pages. The main goal of Web3.0 is to make the Web more intelligent and more connected, by using technologies such as Artificial Intelligence (AI), blockchain technology, Machine Learning (ML) and the Internet of Things (IoT), and, thus, it has become even more interesting for industrial use. With Web3.0, the Web can ‘’understand’’ the meaning of content and available data, and connect them in new and meaningful ways. In addition, Web3.0 also enables direct interaction between devices without human intervention. This IoT provides new opportunities for automation and efficiency of all systems.

Web4.0 is (today’s) fourth generation of the web, characterized by a more collaborative and interactive approach to web development. Web4.0 applications are designed to be more user-friendly and allow users to share information and ideas easily. Some of the most popular Web4.0 applications include social networking sites, blogs, wikis, and video sharing sites. Web4.0 represents a shift from traditional web development models to a more collaborative and user-centered approach, so it is suitable for advanced developments and industrial solutions as well as for the process of acquiring knowledge. Although it seems somewhat futuristic, we can say that it has been with us since 2016, except that the methodologies that we have known since before are much more sophisticated with the use of Artificial Intelligence.

5. Correlations Between I4.0, E4.0 and Web4.0

The individual phases of the development of both industry and education and the World Wide Web, which is involved strongly in all the activities of our everyday life, were presented in the previous chapters, including the individual characteristics of each development stage and interdependencies. [15], [16], [17], [18]
We have reached the current state of the I4.0 industry gradually over the past ten years, somewhat since 2011, when experts saw the big changes in the advancement of technologies as revolutionary – a new industrial revolution. All development phases from Industry I1.0 to the latest Industry I4.0, with basic characteristics, are shown in Table 1. [18]

Table 1. Industry I1.0 to I4.0 comparison

Industrial revolution	Time period	Characteristic technology
Industry I1.0	Late 18th century	Mechanical production and steam power
Industry I2.0	Beginning of the 20th century	Electrical drives and production lines
Industry I3.0	Beginning of the1970s	Digital automation
Industry I4.0	Present	Cyber-physical systems

For the current state of Industry I4.0 we could say that it actually (pre)started with the use of semiconductors, and, later, the first microprocessor controllers. The latter have evolved into more user-friendly and flexible programmable electronic devices that have increased the efficiency and flexibility of production in the form of digital automation significantly. The latter is still carried out today in modern automation systems, except that the devices and systems are more intelligent and better connected, even self-learning.
The general development, not only in the field of Industrial Automation, but also of comprehensive industrial production systems, required a completely new set of necessary skills, a faster way of acquiring them and their faster implementation in the working environment. As a result, it was necessary to find new approaches to providing learning content. The Covid-19 pandemic and the forced use of distance learning contributed to a very large extent, not only when imparting theoretical knowledge, but also practical work at a distance, which represents a greater challenge for teaching staff and students.

Apart from this, other facts dictate changes in the way of teaching content and the approach to lifelong learning. Knowledge acquired during formal education years ago is outdated, and new technologies require completely new knowledge

that needs to be acquired. This is also dictated by migration flows of labour force from different backgrounds, as well as the need for further education or the completion of a certain employee profile. All of the above is covered in the current reformation of higher education with the introduction of micro-credentials, shorter educational activities, with targeted content according to the needs of the employee and the possibility of learning 24/7, anytime and anywhere. [18]
Similar to industrial revolutions, educational revolutions can be categorized based on the stage to which they have evolved over the past centuries. These are shown in Table 2. [19]

Table 2. Education E1.0 to E4.0 comparison

Education revolution	Time period	Technology
Education E1.0	Direct, one-to-one transfer of information	Not present
Education E2.0	Knowledge producing	Limited access
Education E3.0	Beginning of the 1970s	Full support for imparting knowledge
Education E4.0	Replacing classrooms	Digital technology revolution in education

The development of education started decades ago, or even centuries ago, when the teaching was still conservative and mainly passive. The teacher acted as the only source of knowledge from which students received all the necessary information.
Thus, the term Education E4.0 appeared during the rise of the I4.0 industrial revolution, which inevitably affected almost everything, especially in the field of Education. Industry I4.0 requires much more from the current education system, in addition to knowledge of various technologies, including teaching methods.
Educational approaches within E4.0 are related directly to the idea of industry I4.0, where one of the main challenges is the sustainable development of production processes ([20]) and the integration of these processes with digital media ([21]). With Industry I4.0, we aim to achieve a higher level of productivity through process monitoring and real-time diagnostics. I4.0 solutions make it possible to increase the efficiency of production and reduce the loss of time and resources used for sustainable orientation ([22]). Realization of the I4.0 vision requires a well-planned educational process. Industry and education must develop evenly, mutually, and their components must be compatible. Therefore, the foundations of modern education must be laid on the assumptions of the I4.0 industry. E4.0 has derived from this.

A modern approach to education and the delivery of individual professional content cannot be introduced without the development of online technologies. The latter not only contributed greatly to the current methods and possibilities of education, but made it possible in the first place. Figure 4 shows a temporal comparison between the educational revolutions, or the stages, and stages of the development of the Web. [18]

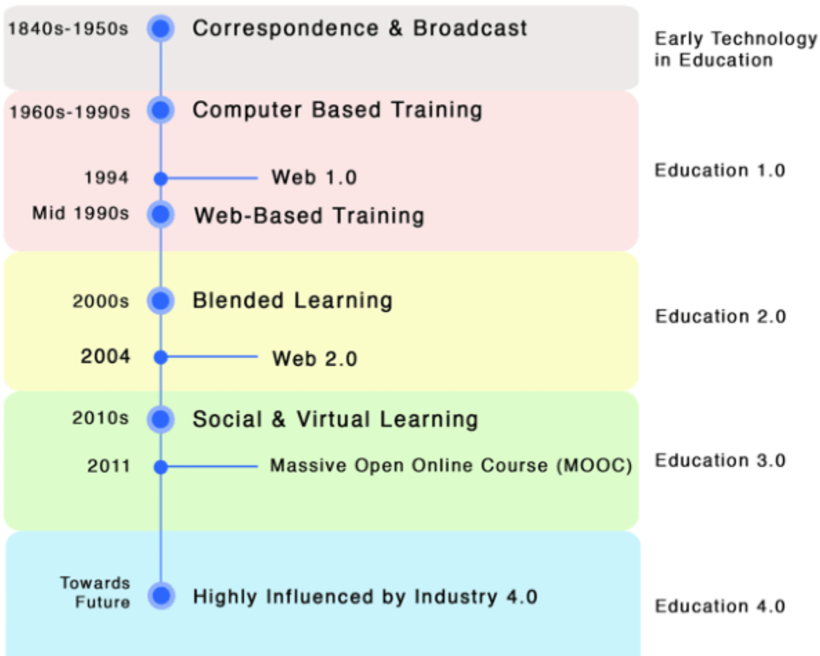

Figure 4.Comparison of Education E1.0 to E4.0 and Web1.0 to Web4.0 [9]

6. Conclusion

The paper begins with the question ''Where are we today in terms of the state of technology?'' and all the ''issues'' that enable, accompany and co-create it. This is not only about the aspect of the state of technology in production systems, which we usually have in mind when we talk about technologies in general, but also about ''technologies'' in the delivery and acquisition of knowledge, and about online technologies that have enabled both the state of development of the industry and the educational process itself and the approach to learning.

New discoveries and knowledge in the field of Technology dictated the introduction of the necessary knowledge into educational processes as well. Thus, with the transformation of the industry from Industry I1.0 to the current state of Industry I4.0, the pedagogical process also changed, from the initial E1.0 to the current E4.0, not only in terms of the necessary learning content, but also new ways of imparting knowledge. Therefore, we can q actually speak of educational revolutions.

Education E4.0 is a new, experience-based education system that, instead of ‘’learning by heart’’ and without understanding what has been learned, responds to the needs of the new world with customized education supported by the use of digital technology. Such an approach to the training of new generations for the needs of Industry I4.0 combines technology, individuality and discovery-based learning, and learners are prepared adequately for the needs of the professions and skills of the future.

With Education E4.0, the concept of education has changed drastically, with some new trends emerging that we are not yet fully aware of. The new education system, which is based on success in life and work and not only on passed exams, points to the necessity of personalized education.

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The Role of Software Engineering in Industry 4.0

Samir Lemeš[*1]

Abstract: *In Industry 4.0, software engineering plays a critical role in enabling and driving the digital transformation of industries. Key roles of software engineering in Industry 4.0 include the development of IoT and connectivity, automation and robotics, data analytics and artificial intelligence (AI), cybersecurity, human-machine interfaces, software integration and system interoperability. Software engineering provides the foundation for Industry 4.0 by developing the software systems and infrastructure required for automation, connectivity, data analysis, and cybersecurity. It enables the digital transformation of industries, driving efficiency, innovation, and new business models.*

Keywords: *Industry 4.0,Software Engineering, Artificial Intelligence, Cybersecurity*

1. Introduction

Data plays a central role in Industry 4.0, as it is the foundation for driving insights, optimization, and decision-making in various industrial processes. In a data-based Industry 4.0, data collection, analysis, and utilization are key components for driving efficiency, productivity, and innovation. Industry 4.0 relies heavily on software engineering to enable and drive its digital transformation. Software engineering focuses on the systematic and structured approach to designing, developing, testing, deploying, and maintaining software systems. It involves applying engineering principles, methodologies, and practices to create high-quality software that meets specific requirements while considering scalability, reliability, maintainability, and usability.

Kipper et al. in [1] tried to identify what competencies are necessary for Industry 4.0. Apart from general and soft skills, such as leadership, self-organization, creativity, problem-solving, innovation, and adaptability, they also emphasized a set of required skills from the contemporary fields, including algorithms, software development and security, and data analysis. The latter skills are the essence of software engineering.

Peres et al. provided a definition and holistic view of Artificial Intelligence (AI) in Industry 4.0 by analyzing its basic building blocks and future trends. They defined Industrial Artificial Intelligence as an interdisciplinary area of

[*1]University of Zenica, Polytechnic Faculty, 72000 Zenica, Bosnia and Herzegovina
ORCID: 0000-0002-3596-645X, E-mail: samir.lemes@unze.ba

research,encompassing machine learning, natural language processing and robotics, or as a ''systematic discipline focusing on the development, validation, deployment and maintenance of AI solutions for industrial applications with sustainable performance'' [2]. Industrial AI faces challenges, such as data availability, data quality, cybersecurity, privacy, and governance. All these challenges are components of software engineering.

Dalzochio et al. investigated machine learning and reasoning for predictive maintenance in Industry 4.0. They identified issues like scalability, latency, and data security as fields deserving further investigation [3].

Aheleroff et al. explored relationships between Digital Twin and mass individualization. They identified suitable Industry 4.0 technologies and a holistic reference architecture model to accomplish the most challenging Digital Twin-enabled applications [4]. They proposed Digital Twin as a Service (DTaaS) under Industry 4.0.

Aceto, Persico and Pescape analyzed ten technological enablers and their interdependencies for Industry 4.0 [5]. Interestingly, they marked the Blockchain enabler as still in exploration and adoption, as opposed to other enabler technologies (IoT, Cloud Computing, Big Data, Artificial Intelligence). They also identified the transition from proprietary software formats to open standards with multiple open-source implementations as one of the challenges for implementation. Although open-source software boosts the application of IoT, the difficulties in estimating the transitioning costs are marked as a challenge. They correctly identified that challenges for open-source software are not in technological issues but in interaction with legacy conditions, corporate culture, market, and regulations [5].

Alladi et al. reviewed the existing blockchain applications in Industry 4.0 and industrial IoT by presenting the current research trends in various industrial sectors and successful commercial blockchain implementations [6]. Liu et al. [7] proposed standardization for blockchain implementation to provide interoperability between different manufacturers. Liu et al. proposed the decentralization of Industry 4.0 by applying blockchain in Product lifecycle management (PLM).

Klingenberg, Borges and Antunestried identified current technologies related to Industry 4.0 and to developed rationale to enhance the understanding of their functions within a data-driven paradigm [8].Their literature survey showed that Industry 4.0 publications focus on enabling technologies that transmit and process data rather than value-creating technologies, which apply data to develop new solutions.Based on their systematic research results, they suggest intensifyingthe research into Data Application technologies.

Ferreira, Armellini and De Santa-Eulaliasystematicallyanalyzed the development of simulation-based research in Industry 4.0 [9]. Their resultsrevealed that hybrid simulation, digital twin and discrete-event simulation are the primary simulation-based approaches in the context of Industry 4.0.

Margariaand Schieweck discussed the difference between the Digital Twin and Digital Thread [10]. The Digital Thread connects real things and their twin models, communication networks, decision algorithms, visualizations, construction, and operation within a mature Industry 4.0 environment. They claim that software and software models are underestimated in their relevance, complexity, challenges, and cost.

Key aspects of software engineering include:

- Analysis and design where user needs and requirements are used to define the functionality and features of a software system;
- Development and programming of computer code using programming languages, frameworks, and development tools;
- Quality assurance and testing to identify and fix defects, validate the software against requirements, and ensure its reliability and quality;
- Deployment and maintenance of the software system in the target environment, monitoring the system's performance, addressing bugs and errors, and implementing updates and enhancements to meet changing user needs;
- Project management in teams, collaborating with clients, managers, and other engineers; and
- Documentation and communication, including technical specifications, user manuals, and system documentation.

To ensure efficient and effective software development, software engineering encompasses variouspractices and methodologies, including Agile, Waterfall, DevOps, and Continuous Integration/Continuous Deployment (CI/CD). It emphasizes use of tools, techniques, and standards to manage complexity, improve productivity, and deliver reliable software solutions. By leveraging data and applying software engineering principles, Industry 4.0 organizations can gain a competitive edge through improved decision-making, optimized processes, and enhanced operational efficiency. Data-based approaches enable agility, innovation, and the ability to respond quickly to changing market demands.

2. Development of IoT and Connectivity

Software engineers design and developsoftware systems that enable the Internet of Things (IoT) and connectivity between various devices, machines, and systems. Software development includes creating protocols, communication frameworks, and interfaces to facilitate seamless data exchange and integration.

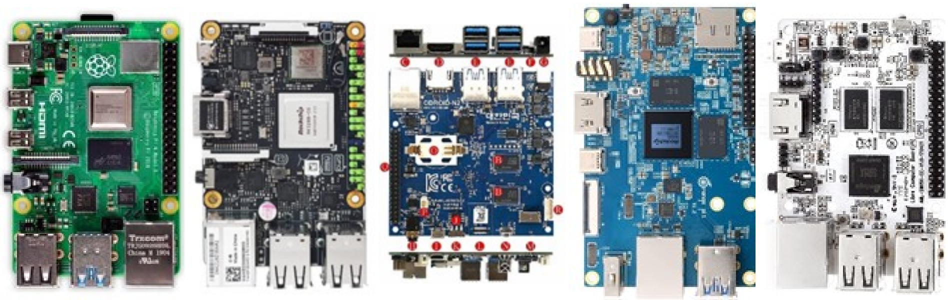
IoT infrastructure is developed using hardware and software solutions [11]. IoT software engineering processes data collected via sensors with visual representation and an intuitive user interface. For IoT software development, three components are required: programming language, development platform, and operating system. In exceptional cases, IoT devices can be built without an operating system, using only PLCs (Programmable Logic Controllers). PLCs are programmed for a single application and do not require an operating system to run the application (Figure 1). Pocket-size computers, such as Raspberry Pi, can be used as a basis for IoT devices but require an operating system. They can be programmed to run multiple software applications simultaneously. However, the software is needed to operate both devices.

Raspberry Pi Arduino PLC

Figure 1. Raspberry Pi computer needs an operating system, unlike Arduino PLC [12]

Both types of IoT devices can be used for industrial applications. PLC generally offers more automation-specific processing than computers. PLCs include hardware and software watchdogs. Software watchdogs make sure the program is running as desired. For example, poor programming could lead to code execution in an endless loop, causing a harmful and potentially dangerous out-of-control situation [13]. Hardware watchdogs monitor the peripheral devices connected to the PLC, such as switches, sensors, and actuators. These watchdogs are not built-in in Raspberry Pi, and the software routines must be developed or found to deliver this functionality.

Commercially available industrialized products cost more than systems created from consumer electronics controllers but include significant mission-specific hardware and software benefits. Do-it-yourself (DIY) options can be cost-effective but require considerable attention to integrate hardware and software [13] properly.



Raspberry Pi *Asus Tinker Board* *Odroid N2+* *Orange Pi* *Libre Computer Board*

Figure 2. Examples of pocket-size computers used for the development of IoTdevices

IoT devices based on Raspberry Pi or similar computers (Figure 2) consist of low-powered processing units, small RAMs, restricted storage and communication I/O ports used to connect peripherals. They often have built-in network interfaces (Ethernet, Wi-Fi, Bluetooth, Zigby). They use lightweight operating systems due to limited storage capacity. These are some of the most frequently used operating systems in Industrial IoT devices:

- **Contiki-NG**: open-source OS for resource-constrained IoT devices (http://www.contiki-os.org/)
- **FreeRTOS**: a real-time operating system for microcontrollers and small microprocessors, with long-term support (LTS)from Amazon(https://www.freertos.org/)
- **Mbed OS**: open-source OS for IoT devices based on an Arm Cortex-M microcontroller with a broad range of connectivity options (https://os.mbed.com/mbed-os/)
- **Nucleus**: real-time operating system produced by the Embedded Software Division of Mentor Graphics, a Siemens Business, supporting 32- and 64-bit embedded system platforms (https://www.plm.automation.siemens.com/global/en/products/embedded/nucleus-rtos.html)
- **OpenWrt**:open-source project for embedded operating systems based on Linux, primarily used on embedded devices to route network traffic (https://openwrt.org/)
- **Raspbian**: a free operating system based on Debian Linux and optimized for the Raspberry Pi hardware (http://www.raspbian.org/)
- **Tizen**: Linux-based free, open-source IoT OSdeveloped by Samsung Electronics (https://www.tizen.org/)
- **VxWorks**: real-time operating system supporting application deployment through containers, developed as proprietary software by Wind River Systems (https://www.windriver.com/products/vxworks)

- **Windows IoT** (formerly Windows Embedded): a component of the Microsoft Windows 10 OS for IoT devices that run on Arm and x86/x64 devices (https://developer.microsoft.com/en-us/windows/iot/)
- **Zephyr**: a small real-time operating system for connected, resource-constrained and embedded devices supporting multiple architectures (https://zephyrproject.org/)

Software for IoT is developed using different programming languages. **C** and **C++**are programming languages written with a hardware perspective in mind. Since most introductory courses for computer programming are based on these languages, they are the most widely spread languages. Their direct competitor is **Java**. Initially known as the programming language for mobile devices and web-based applicationsmainly because of its high portability, Java is compatible with various peripheral devices and is well-suited for IoT devices. **Python**is a good choice for IoT applications,as it can easily handle data-heavy applications. **JavaScript** is often used for connectivity and interoperability. It can be applied for both back-end and front-end processes. A low entry level and many specialized coders on the market are the main benefits of JavaScript. Although the **Go**language is a relatively new programming language, it has been widely implemented in various IoT projects due to its multipleuses, such as optimized coding.

The software development process for IoT devices differs considerably from the traditional desktop computer process. Developing software for IoT involves unique considerations due to the distributed nature of IoT systems and the diversity of devices and protocols involved. A typical software development process for IoT consists of the following phases:

- Requirements gathering: Understand the business objectives and functional requirements of the IoT system. Identify the devices, sensors, actuators, and data sources involved. Determine the desired interactions, data flows, and integration points.
- Architecture and design: Design the overall system architecture, including the interactions between IoT devices, edge devices, gateways, cloud platforms, and user interfaces. Consider factors like scalability, reliability, security, and data management. Define protocols, APIs, and data formats for communication between devices and other components.
- Device selection and integration: Select appropriate IoT devices based on the requirements and architecture. Develop or configure drivers and protocols to enable communication and integration of devices within the system. Ensure compatibility and interoperability among different devices.
- Connectivity setup: Set up the necessary connectivity infrastructure, such as Wi-Fi, Bluetooth, or cellular networks, to establish

communication between devices and gateways and configure network settings, security protocols, and authentication mechanisms.

- Data management: Define the data collection, storage, and processing mechanisms. Determine the data flow, including local data processing at the edge or cloud-based processing, and design databases or data repositories to store and manage IoT data efficiently.
- Software development: Develop the software components required for the IoT system, including firmware for devices, software for gateways and edge devices, cloud-based applications, and user interfaces. Implement functionalities such as data acquisition, device control, data processing, analytics, and visualization.
- Security implementation: Incorporate security measures to protect the IoT system from threats. Implement secure communication protocols, encryption, access control, and authentication mechanisms. Consider data privacy and compliance with regulations.
- Testing and validation: Conduct thorough testing of the IoT system components, including devices, connectivity, data transmission, and software functionalities. Perform integration testing to ensure seamless communication and data flow. Validate the system against the defined requirements and use cases.
- Deployment and monitoring: Deploy the IoT system in the target environment. Set up monitoring and management tools to track device performance, connectivity, and data flow. Implement mechanisms for remote device management, software updates, and troubleshooting.
- Continuous improvement: IoT systems often require constant iteration and improvement. Gather feedback, monitor system performance, and analyze user behaviour to identify areas for enhancement. Regularly update software components, address security vulnerabilities, and add new features based on user needs and evolving technologies.

It is crucial to collaborate with cross-functional teams throughout the software development process, including hardware engineers, data scientists, network specialists, and domain experts, to ensure a holistic approach to IoT system development.

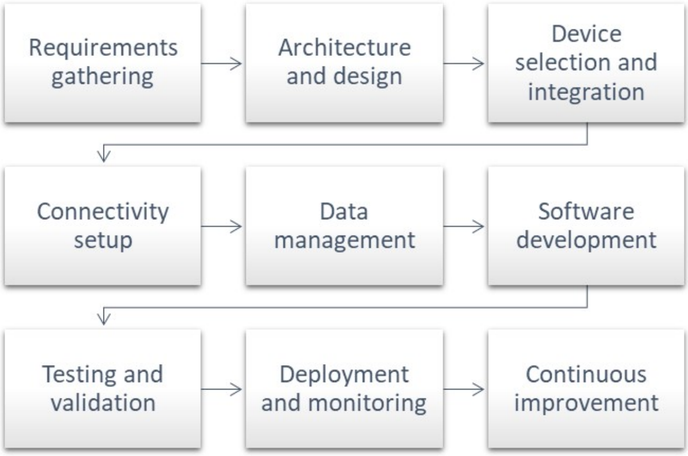


Figure 3. The software development process for IoT

The connectivity aspect of IoT refers to the ability of devices, sensors, and systems to connect and communicate with each other, enabling data exchange and enabling the functioning of an IoT ecosystem. Connectivity is a fundamental requirement for IoT systems to operate effectively.

IoT devices use various communication protocols to exchange data. Common protocols include Wi-Fi, Bluetooth, Zigbee, Z-Wave, LoRaWAN, cellular networks (2G/3G/4G/5G), and Ethernet. The selection of a communication protocol depends on factors like range, data rate, power consumption, and specific use case requirements. Wireless connectivity enables devices to communicate without physical wired connections. Wi-Fi and Bluetooth are widely used for short-range communications within a local area, while cellular networks provide broader coverage and enable devices to connect over long distances. Low-power protocols like Zigbee and Z-Wave are suitable for home automation and smart devices.

Cloud platforms are frequently utilized in IoT systems to store, process, and analyze data from connected devices. IoT devices establish connections to the cloud to transmit data, receive commands, and access cloud-based services. Cloud connectivity enables centralized management and data storage and enables advanced analytics and machine learning algorithms to process data at scale.

In IoT systems, edge computing often comes into play to process and analyze data closer to the source, reducing latency and bandwidth requirements. Gateways act as intermediaries between devices and the cloud, aggregating data from multiple devices and enabling communication with the cloud infrastructure.

Wireless Standard	Power	Transmission Range (typical)	Data Rates
Bluetooth	Medium	1 to 100 m	1 to 3 Mbps
Bluetooth LE	Lower	>100 m	125 kbps to 2 Mbps
LoRaWAN	Low	10 km	0.3 to 50 kbps
NB-IoT	Low	<35 km	20 kbps to 5 Mbps
NFC	Low	<10 cm	106 to 424 kbps
Sigfox	Low	3 to 50 km	100 to 600 bps
6LoWPAN	Low	100 m	0 to 250 kbps
802.11/Wi-Fi	Medium	100 m to several km (with boosters)	10 to 100+ Mbps
802.15.4/Zigbee	Low	10 to 100 m	20 to 250 kbps
Z-Wave	Low	15 to 150 m	9.6 to 40 kbps

Figure 4. Features of major wireless connectivity technologies used in IoT [14]

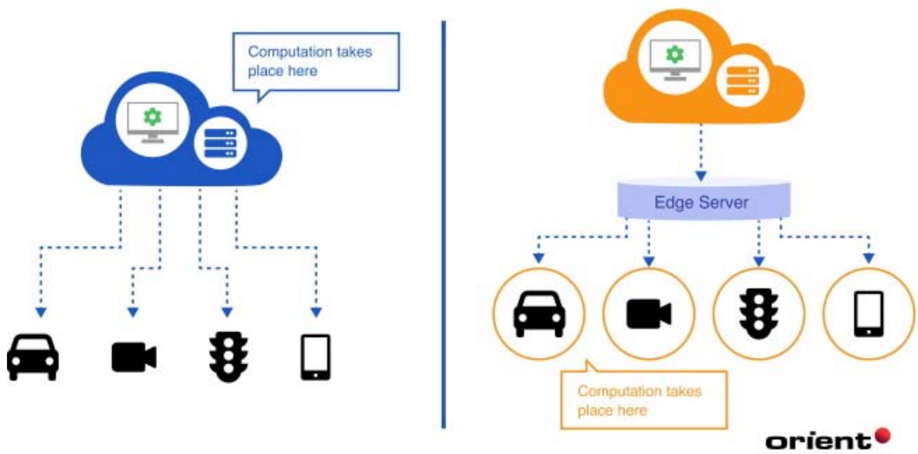


Figure 5. Difference between Edge computing and Cloud computing [15]

IoT platforms provide tools and services that facilitate connectivity and data management in IoT systems. They offer APIs (Application Programming Interfaces) that enable developers to integrate devices, collect data, and control device behaviour. These APIs allow seamless communication between devices, gateways, and cloud services, simplifying the development and integration process.

IoT systems often involve many devices, which require scalable network management. Network management tools and techniques ensure smoothoperation, efficient resource utilization, and device connectivity and performance monitoring.

Finally, security is a critical concern in IoT connectivity. As IoT systems involve numerous interconnected devices and data exchanges, security measures are necessary to protect against unauthorized access, data breaches, and cyber threats. Encryption, authentication mechanisms, secure communication protocols, and regular software updates are essential to maintain the security and privacy of IoT systems.

3. Automation and Robotics

Industry 4.0 emphasizes use of automation and robotics to improve efficiency and productivity. Software engineers are responsible for developing the software that controls and manages these automated systems. They design algorithms, develop control systems, and program robots to perform complex tasks in logistics, manufacturing, and other industries.

Robot Operating System (ROS) is a popular open-source framework for developing and controlling robots. It provides a collection of software libraries and tools that facilitate communication, hardware abstraction, sensor integration, and robot control. ROS enables the development of modular and interoperable robot software components.ROS is released as distributions. Some releases come with long-term support (LTS), which means better stability is obtained through extensive testing. Other distributions have shorter lifetimes butsupport more recent platforms and versions of their constituent ROS packages [16].

ROS distributions require an operating system and are tailored for installing different OSs. ROS Foxy Fitzroy runs on Ubuntu (Debian) Linux and Windows 10. ROS Noetic Ninjemysis made for Ubuntu Linux. ROS Humble Hawksbill, ROS Iron Irwini, and ROS Rolling Ridley run on Ubuntu (Debian), Windows 10 and RedHat Linux. ROS Melodic Moreniais primarily targeted at Ubuntu, though other Linux systems, as well as Mac OS X, Android, and Windows, are supported to varying degrees [16].

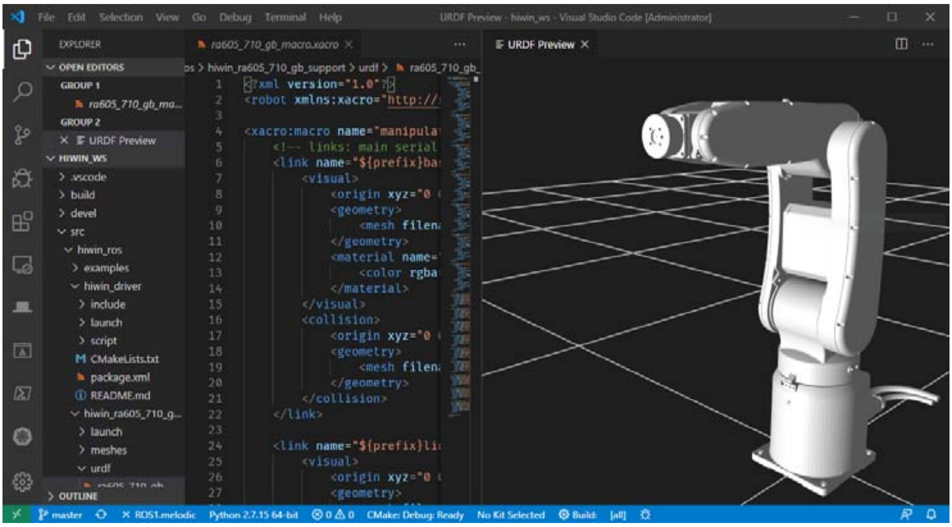


Figure 6. Robot Operating System (ROS)integrated with Microsoft Azure services [17]

Industry 4.0 envisions close collaboration between humans and machines. Software engineers are responsible for designing intuitive and user-friendly human-machine interfaces (HMIs) that enable effective communication and interaction between operators and automated systems. They focus on usability, visualizations, and integrating different technologies to create seamless interfaces. Human-Machine Interfaces are software applications that provide a graphical user interface (GUI) for operators to interact with automation systems and robots. HMIs allow users to monitor system status, control processes, and receive feedback. They often include features like data visualization, alarms, and data logging.

Smart cyber-physical systems require new types of interfaces for smooth human-machine interaction, primarily when operating in dark or dustyenvironments. New types of HMIs are being implemented in Industry 4.0, such astouch-screen displays, voice interfaces, gesture interfaces, and ARtools [18].Touch-screen displays have been in use for more than 20 years already. Modern touch interfaces allow managing machines even in gloves. In Industry 4.0, voice interfaces have limited use due to noisy conditions. Where available, voice recognition controls appliances on the shop floor and asks questions regarding machines' outputs. Gesture control enables touchless manipulation of industrial devices using wired or wireless gloves, cameras, or hand-tracking controllers. Augmentedreality combines simulated environments with real-world video to allow control of machinery or computers. It can assist the assembly process by projecting leading lines or alphanumerical instructions on an assembly floor or using AR glasses, thus reducing the risk of mistakes.

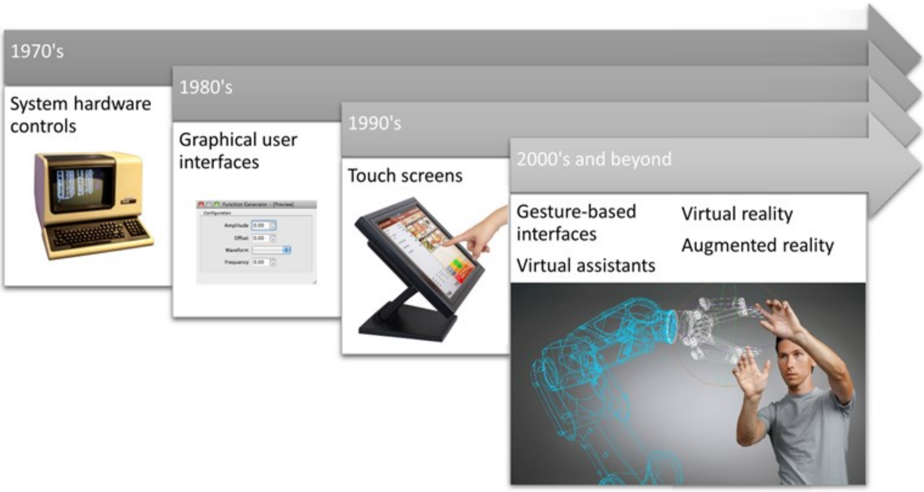


Figure 7. Evolution of human-machine interfaces

Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM)software are used in robotics and automation systems' design and manufacturing stages. CAD tools enable engineers to design and model robotic systems, while CAM software translates these designs into machine instructions for manufacturing processes like milling, cutting, or 3D printing. Typical CAD/CAM user needs only functional skills for manipulating graphic data and designing 3D models. In some cases, software engineering and computer programming skills are required to automate the design process and perform advanced engineering tasks such as shape optimization, statistical analysis, or photorealistic visualization. Simulation software allows engineers to virtually model and test automation and robotic systems before physical implementation. Digital Twin is a technology that creates a virtual replica of physical systems, enabling real-time monitoring, analysis, and optimization. Simulation and Digital Twin software help optimize system performance, identify bottlenecks, and predict maintenance needs.

Artificial Intelligence (AI) and Machine Learning (ML) technologies are increasingly integrated into automation and robotics systems. Software applications leverage AI and ML algorithms to enable advanced capabilities like machine vision, object recognition, autonomous decision-making, and predictive maintenance. These technologies enhance the flexibility, adaptability, and intelligence of automation and robotics systems.

Workflow and process automation software enable the automation of repetitive tasks, coordination of processes, and workflow optimization. These tools provide visual programming interfaces or rule-based engines to define workflows, trigger actions, and integrate different systems and components. They improve operational efficiency, reduce errors, and enhance collaboration.

With increased connectivity and digitalization, robust cybersecurity solutions are crucial for protecting automation and robotics systems from cyber threats. Software applications focused on cybersecurity provide features like intrusion detection, encryption, access control, and vulnerability management to safeguard industrial systems.
All these software applications form a technology stack that enables automation, control, optimization, and intelligent decision-making in Industry 4.0 robotics and automation systems. They increase productivity, efficiency, and flexibility in manufacturing and other industries.

4. Data Analytics and Artificial Intelligence

In Industry 4.0, there is a significant focus on leveraging data and applying artificial intelligence (AI) techniques for improved decision-making and predictive analytics. Software engineers develop applications that collect, process, and analyze large volumes of data generated by smart sensors, machines, and systems. They also build AI models and algorithms to extract insights, optimize processes, and enable predictive maintenance.Artificial Intelligence (AI) contributes to Industry 4.0 in different areas: machine learning, computer vision, natural language processing for HMIs, intelligent decision support and cognitive automation.
In recent years, machine learning has led to remarkable progress in many application areas, all thanks to the availability of more significant amounts of data and advances in computer technology that have enabled data processing in increasingly complex machine learning models. Machine learning (ML) is a component of artificial intelligence where, by applying information technologies to existing data, which are seemingly unrelated, and appropriate algorithms, one tries to discover new knowledge that could then be used to solve new problems. Machine learning algorithms can be classified into several categories depending on the learning method:

- supervised learning,
- unsupervised learning,
- assisted learning, and
- deep learning.

Supervised learning implies that for each instance from the training set, the class to which it belongs is also known, i.e., it is necessary to manually classify the training data so that the algorithm can learn to do it on new data [19, 20]. It is most often applied in cases of classification and regression. Unsupervised learning does not require human intervention, and the algorithm recognizes patterns in the training data. Reinforced learning means learning where the model's performance is supported by appropriate reward and punishment depending on what results the model gives. In deep learning, we have models with multiple layers of artificial neural networks that can make intelligent decisions based on large amounts of data.

Computer vision techniques use AI to enable machines to interpret and understand images and videos. It finds applications in quality inspection, object recognition, defect detection, and even autonomous robotics.

Natural Language Processing (NLP) enables machines to understand and process human language. It facilitates human-machine interaction, voice-based control systems, chatbots, and natural language interfaces for data querying and analysis.

AI technologies provide decision support systems that assist operators, managers, and engineers in making informed decisions. They analyze data, provide insights, and recommend actions based on historical and real-time information. Cognitive automation combines AI technologies with robotic process automation (RPA) to automate complex tasks that require cognitive abilities like reasoning, learning, and understanding. It helps streamline administrative processes, reduce errors, and enhance efficiency.

By leveraging data analytics and AI in Industry 4.0, organizations can gain valuable insights, optimize processes, improve productivity, enhance quality control, enable predictive maintenance, and drive innovation. These technologies empower businesses to make data-driven decisions and unlock new opportunities for growth and competitive advantage.

ML and AI require a significant amount of computing power, which is mainly used in cloud computing. However, thousands of IoT devices represent a significant potential which is not utilized at full capacity. Most of the time, IoT devices are idle, creating a possibility to supplement the computing power in the cloud. Cloud computing is usually charged per usage, and operating costs can be very high. Edge computing is a technology trying to utilize distributed computing resources from the network of connected IoT devices.

4.1.Edge computing

Internet of Things devices are increasingly used in industry, thus, the amount of data they generate increases. In the case of data processing in the cloud, the data must first be transferred via an Internet connection, undergo processing, and only then be returned to an IoT device or another terminal device [21]. This, in addition to increasing the application's response time, also represents a growing challenge for the throughput of Internet connections due to the increased volume of data. This is especially distinct in cases where machine learning is applied in computer vision applications. For this reason, previous research suggests using edge computing to create solutions that fit the application with IoT devices so that their potential can be used to the best advantage.

In contrast to the cloud approach, where computing resources are centralized at one remote location, with edge computing, data processing approaches the datasource itself [22, 23]. Here, one must consider that edge devices usually have weaker computing resources in terms of accommodation and data processing capabilities. For this reason, it is most often resorted to combining cloud and edge computing, where more demanding tasks, such as the machine learning process, take place in the cloud, which has much larger resources adapted for that purpose. In contrast, trained models can be adapted to limited edge resources and thus ensure the functioning of the process inferences close to the data source. Edge computing is a relatively new technology that is not yet standardized. Many platforms still work through incompatible protocols, which is a limitation during implementation [24].

Although machine learning in edge computing has advantages over cloud computing, certain trade-offs are necessary, including cost, reliability, network infrastructure, data privacy, and storage space. Material costs are rising to support machine learning in edge computing, but with large volumes of cloud transactions, cloud communication costs for the device are also increasing. Reliability significantly depends on the speed of Internet access. Edge computing eliminates delays associated with network resources. As some applications require data to be stored locally, keeping specific data on the device can improve data privacy. The IoT devices on which edge computing is based do not have enough storage space, which introduces a new challenge to storage resources.

Web 3.0 is a new concept that uses blockchain technologies to decentralize the Internet [25]. It is based on several principles: decentralization, no permissions, payment is exclusively in cryptocurrencies, and it does not use intermediaries to establish user trust but relies on a distributed blockchain system. Blockchain creates a faster, decentralized, and more secure computing environment. In contrast, Edge computing provides the supporting infrastructure that enables fast and reliable transactions, especially with advanced implementations of blockchain proof of stake (PoS) [26].

5. Cybersecurity

With the increased connectivity and digitalization in Industry 4.0, the importance of cybersecurity cannot be understated. Software engineers developsecure software systems, implementing robust authentication and encryption mechanisms and addressing vulnerabilities and threats. They work to ensure the integrity, confidentiality, and availability of data and systems in the industrial environment.

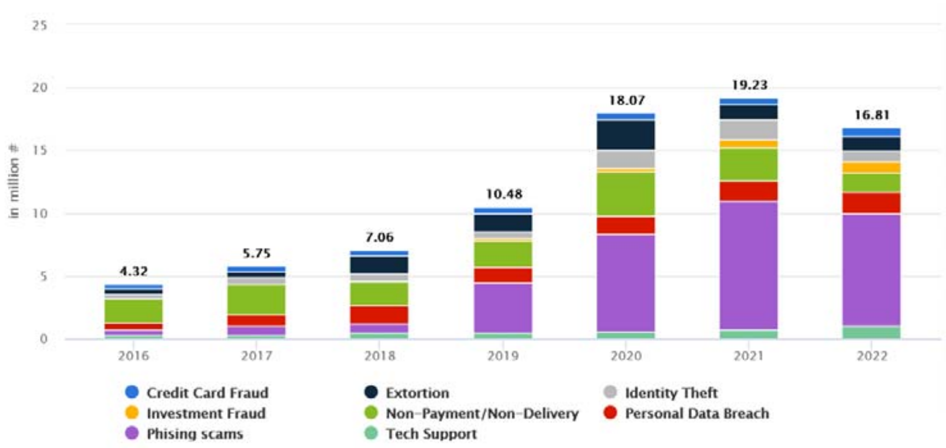


Figure 8. Recorded cyber-attacks [27]

Figure 8 illustrates the increase in cyber-attacks in the past seven years, indicating that phishing scams are the most frequently recorded cyber-attacks. Figure 9 reveals that in 2022 manufacturing had the highest share of cyber-attacks among the leading industries worldwide. During the examined year, cyber-attacks in manufacturing companies accounted for nearly 25% of the total cyber-attacks, even more than finance and insurance [28].

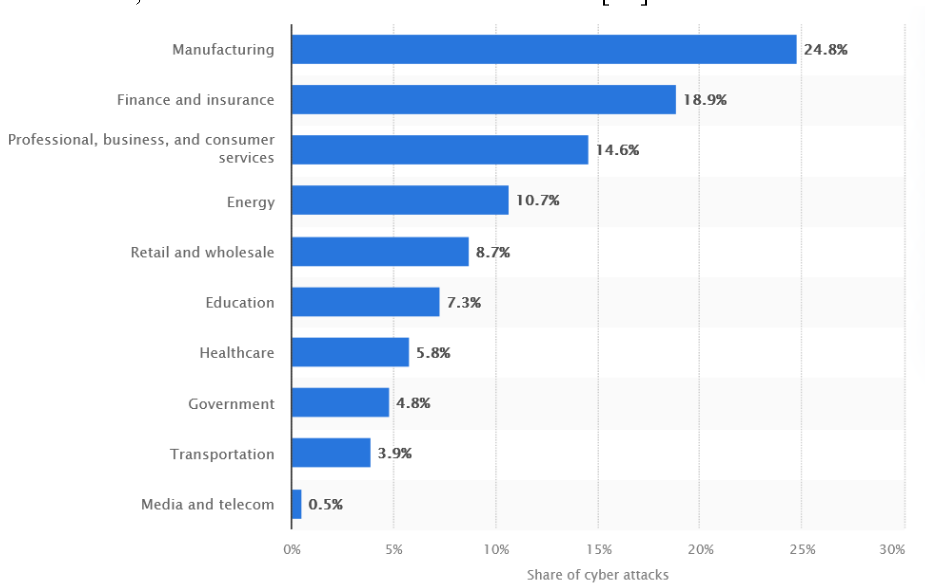


Figure 9. Distribution of cyber-attacks across worldwide industries in 2022 [28]

Cybersecurity is paramount in software engineering due to the increasing reliance on digital systems, interconnected networks, and the ever-evolving threat landscape. Cybersecurity is crucial in software engineering. Cybersecurity ensures that sensitive data, such as personal information, financial records, and intellectual property, remains confidential and protected from unauthorized access. This is particularly important in finance, healthcare, and government sectors, where data privacy regulations mandate strict protection measures. But statistical data shows that the increasingly automated and computerized manufacturing sector is exposed to many cyber-attacks. Figure 10 shows how the number of IoTcyber-attacks worldwide amounted to over 112 million in 2022. Over the recent years, this figure has increased significantly from around 32 million detected cases in 2018. In the latest measured year, the year-over-year increase in the number of IoTmalware incidents was 87% [29].

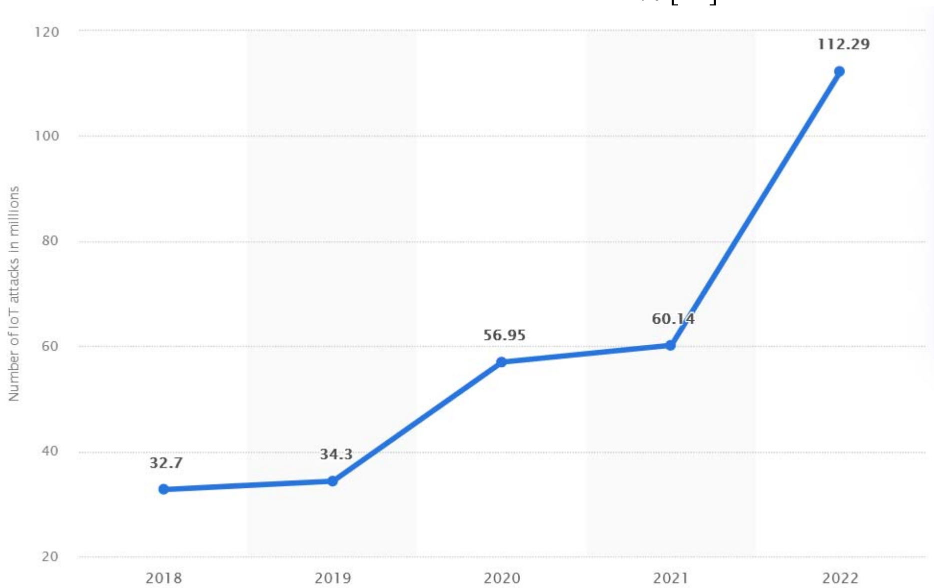


Figure 10. The annual number of IoT malware attacks worldwide from 2018 to 2022 [29]

Cybersecurity measures protect software systems from unauthorized modifications, tampering, or unauthorized access. By ensuring system integrity, cybersecurity prevents unauthorized individuals from altering critical functionalities, manipulating data, or introducing malicious code that could compromise the system's reliability and stability. Cybersecurity helps maintain the availability and continuous operation of software systems. It safeguards against distributed denial-of-service (DDoS) attacks, which overload systems with excessive traffic, causing services to become inaccessible. By implementing robust security measures, software engineers can prevent or mitigate such attacks, ensuring system availability for users.

Security breaches and cyber-attacks can lead to substantial financial losses, lawsuits, and reputational damage for organizations. The recovery cost from a security incident, investigating the breach, notifying affected parties, and restoring systems can be significant. Organizations can reduce the risk of breaches and the associated financial and reputational repercussions by prioritizing cybersecurity in software engineering.
Cybersecurity measures, such as secure coding practices and vulnerability management, help defend against malware and ransomware attacks. These attacks can compromise systems, encrypt data, and demand ransom for its release. Robust security practices, including regular patching, intrusion detection systems, and secure software development, can significantly mitigate the risk of malware and ransomware infections.
Many industries have regulatory requirements that mandate strong cybersecurity measures. Organizations must adhere to regulations such as the European General Data Protection Regulation (GDPR) or the Payment Card Industry Data Security Standard (PCI DSS). By incorporating cybersecurity best practices into software engineering processes, organizations can demonstrate compliance with these regulations.
The cybersecurity landscape constantly evolves, with new threats and attack vectors emerging regularly. Software engineers need to stay abreast of the latest vulnerabilities, exploits, and security best practices to develop secure software. Software engineers can stay one step ahead of potential attackers by continuously updating security measures and addressing emerging threats.In an increasingly digital world, customers value trust in their software systems. Organizations can demonstrate their commitment to protecting customer data and providing secure services by prioritizing cybersecurity. This fosters trust and confidence among users, leading to stronger customer relationships and brand loyalty.
Cybersecurity is essential in software engineering to protect data, ensure system integrity and availability, mitigate financial losses and reputational damage, defend against malware and ransomware, comply with regulations, address emerging threats, and foster customer trust. Incorporating robust cybersecurity practices throughout the software development lifecycle is crucial for building secure and resilient software systems in today’s interconnected and threat-prone environment.
Cybersecurity is critical to Industry 4.0 as integrating digital technologies, interconnected systems, and the Internet of Things (IoT) introduce new security risks. Designing a secure architecture is crucial for Industry 4.0 systems, involving implementing defense-in-depth principles, segmenting networks, and ensuring secure communication protocols between devices, sensors, and systems. Security should be considered at every architecture layer, from edge devices to cloud infrastructure.

IoT devices and sensors in Industry 4.0 systems should have built-in security features, such as strong authentication mechanisms, encryption for data in transit and at rest, secure boot processes, and over-the-air firmware updates to address vulnerabilities and patch security flaws.

Industry 4.0 networks should have robust security measures in place. Secure configuration of network devices, firewalls, intrusion detection and prevention systems, and regular network traffic monitoring for anomaliesis necessary. Network segmentation can help limit the impact of potential breaches and contain security incidents.

Strong authentication mechanisms, such as multi-factor authentication, should be implemented to ensure that only authorized individuals can access critical systems and data. Access control policies should be enforced to restrict privileges based on roles and responsibilities, limiting access to sensitive information and functions.

Industry 4.0 systems involve the collection and processing of vast amounts of data. Encryption should be employed to protect data both in transit and at rest. Privacy considerations, including compliance with data protection regulations, should be addressed to safeguard personal and sensitive information.

Implementing security monitoring tools and techniques allows for continuous monitoringof Industry 4.0 systems. Detecting abnormal behaviour, intrusion attempts, and potential security incidents is necessary. Security Information and Event Management (SIEM) proprietary solutions, log analysis, and anomaly detection can help promptly identify and respond to threats.

Establishing an incident response plan is essential to respond to cybersecurity incidents effectively. Roles and responsibilities, incident detection and reporting processes, and procedures for containment, eradication, and recovery should be defined. Regular testing and simulations of incident response plans help ensure their effectiveness.

Cybersecurity awareness and training programs should be provided to employees to educate them about best practices, potential threats, and their roles and responsibilities in maintaining security. These programs helpfoster a cybersecurity culture and reduce the risk of human error leading to security incidents.

Industry 4.0 systems often involve multiple vendors and suppliers. It is essential to ensure they have robust cybersecurity practices, such as performing due diligence when selecting vendors, establishing contract security requirements, and regularly auditing and monitoring their security measures.

The ISO 27000 family of international standards is published jointly by the ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission). These standards enable organizations to manage the security of digital assets, and there is an internationally recognized certification scheme for organizations, similar to the ISO 9000 certification system.

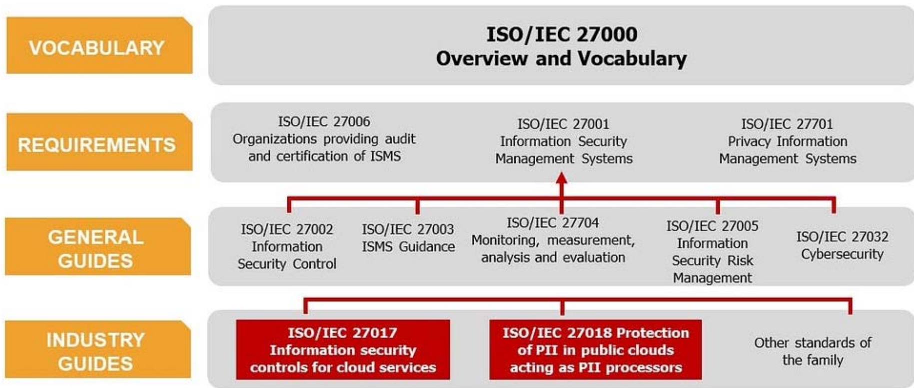


Figure 11. The ISO 27000 series of standards[30]

The ISO 27001 standard provides a framework for establishing, implementing, maintaining, and continually improving an information security management system (ISMS). Implementing ISO 27001 can significantly enhance cybersecurity in Industry 4.0 by addressing essential security requirements and best practices. ISO 27001 requires organizations to conduct a systematic risk assessment to identify and assess information security risks. The risk assessment includes identifying assets, assessing vulnerabilities and threats, and determining the impact and likelihood of risks. Organizations can proactively identify potential cybersecurity risks in Industry 4.0 systems by conducting comprehensive risk assessments and implementing appropriate controls to mitigate them.

ISO 27001 provides a set of controls outlined in Annex A, which covers various domains of information security. These controls include technical measures, policies, procedures, and organizational measures organizations can implement to protect their information assets. By implementing these controls, organizations can enhance the security of their Industry 4.0 systems and address specific cybersecurity challenges.

ISO 27001 emphasizes the importance of secure software development practices. It encourages organizations to follow safe coding guidelines, conduct security testing, and ensure secure configuration and management of software and systems. Adhering to these practices in Industry 4.0 software development helps identify and mitigate vulnerabilities and reduce the risk of cyber threats.

Industry 4.0 systems often involve multiple vendors and suppliers. ISO 27001 promotes effective supplier management practices, including assessing the security capabilities of suppliers, defining security requirements in contracts, and establishing processes for monitoring and auditing suppliers' security measures.

Organizations can mitigate the risk of vulnerabilities introduced through the supply chain by ensuring that suppliers meet appropriate security standards.

ISO 27001 requires organizations to establish incident response and business continuity management processes. These processes include identifying and responding to security incidents, conducting incident investigations, and ensuring timely recovery and restoration of critical systems. Organizations can effectively mitigate the impact of cybersecurity incidents in Industry 4.0 systems by having robust incident response and business continuity plans.

ISO 27001 emphasizes the importance of security awareness and training for employees. It encourages organizations to provide regular security awareness programs to educate employees about information security risks, policies, and procedures. By raising employee awareness and knowledge about cybersecurity, organizations can reduce the risk of human error and improve the overall security posture of Industry 4.0 systems.

ISO 27001 promotes a culture of continuous improvement in information security management. It requires organizations to conduct regular internal audits, management reviews, and risk assessments to identify areas for improvement. By continuously monitoring and assessing the effectiveness of security controls, organizations can adapt to emerging cybersecurity threats and maintain compliance with evolving standards and regulations.

Implementing ISO 27001 standards in Industry 4.0 systems provides a systematic and comprehensive approach to cybersecurity. It helps organizations identify and mitigate security risks, establish robust controls, ensure secure development practices, manage suppliers, respond to incidents, and foster a culture of security awareness. By adhering to ISO 27001 standards, organizations can strengthen their cybersecurity posture, protect critical assets, and ensure the secure operation of Industry 4.0 systems.

By considering these cybersecurity measures in the design, implementation, and operation of Industry 4.0 systems, organizations can mitigate identified risks, protect the most critical assets, and ensure the reliability and integrity of their operations in the face of evolving cybersecurity threats.

6. Software Integration and System Interoperability

In Industry 4.0, there is a need to integrate various software systems and ensure interoperability between heterogeneous devices and platforms. Software engineers work on integrating software components, designing APIs (Application Programming Interfaces), and creating middleware solutions that enable seamless data flow and communication across different systems and technologies.

Software integration is crucial in Industry 4.0, enabling seamless connectivity and interoperability of diverse systems, devices, and software applications.

Figure 12 shows this development in a factory of Industry 4.0 and introduces the principles of vertical and horizontal integration [31]. Vertical integration means merging planning and development with production. Horizontal integrationis performed with the networked production, increased interconnections and information interexchangeamong departments and companies. Different software solutions support all these services and resources, which should also be integrated vertically and horizontally to enable digital factories within Industry 4.0.

Figure 12. Vertical and horizontal integration under Industry 4.0 [31]

Industry 4.0 integrates various systems, such as enterprise resource planning (ERP) and manufacturing execution systems (MES), supply chain management systems, and IoT platforms. Software integration enables these systems to communicate and share data in realtime, facilitating end-to-end visibility and control over the entire value chain. The proliferation of IoT devices and sensors in Industry 4.0 requires integrating their data and functionality into existing software systems, IoT platforms, data ingestion mechanisms, and sensor data processing capabilities to enable real-time data collection, analysis, and decision-making.

Software integration enables the integration and consolidation of data from various sources, including sensors, machines, enterprise systems, and external data feeds. This integrated data can then be analyzed using advanced analytics techniques to derive insights, support decision-making, and drive optimization in predictive maintenance, quality control, and resource utilization.

Many organizations have existing legacy systems that need to be integrated with new Industry 4.0 technologies and platforms. Software integration allows for the seamless connection between legacy systems and modern applications, enabling data exchange and leveraging the functionalities of both systems. Legacy systems can be retrofitted by introducing low-cost IoT sensors and controllers, thus allowing the automation of old analog systems.

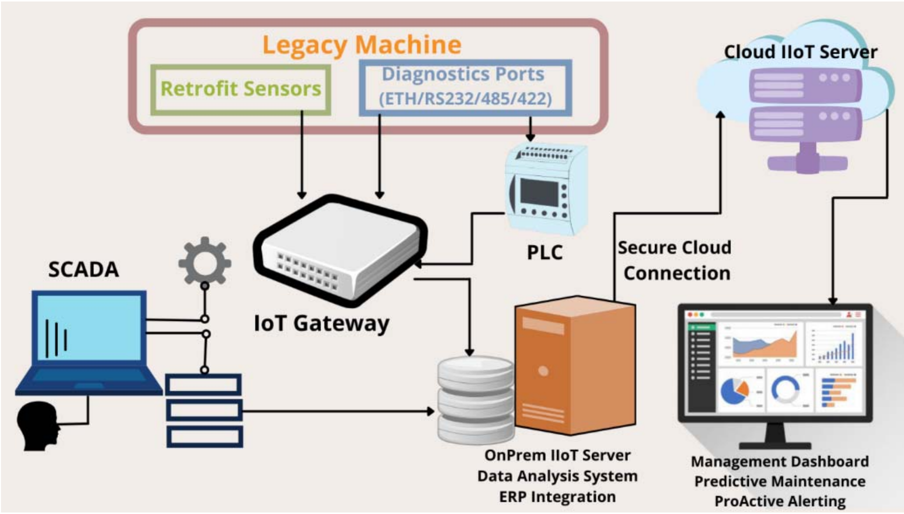


Figure 13. Retrofitting legacy machineswith IoT [32]

Figure 14. Retrofitting boosts the machine's productivity, uptime, reliability, and efficiency [33]

Software integration in Industry 4.0 often involves addressing the challenge of diverse systems and technologies from different vendors. Standardization and adherence to interoperability standards, such as OPC UA (Open Platform Communications Unified Architecture), MQTT (Message Queuing Telemetry Transport), and RESTful APIs (Representational State Transfer), facilitate smooth integration and communication between systems. Software integration enables the integration of cloud platforms and services with on-premises systems and edge devices. This allows for scalable computing power, storage, analytics capabilities, and real-time decision-making at the edge of the network.

Application programming interfaces (APIs)are a key enabler for software integration in Industry 4.0. APIs enable interaction between the different software applications and systems and share data in a standardized and controlled manner. They provide the interfaces and protocols for seamless integration, allowing the developers to build integrations easily.

Effective software integration in Industry 4.0 ensures that disparate systems, devices, and applications work harmoniously, enabling data-driven decision-making, process optimization, and improved operational efficiency. It allows the seamless flow of information across the entire value chain, enhances collaboration, and supports the realization of the full potential of Industry 4.0 technologies.

6.1. Software development process

The software development process is divided into smaller, parallel, or sequential steps or subprocesses to improve the design or management of the software product. It is also known as the Software Development Life Cycle (SDLC). Traditional methods are based on a series of development steps, such as requirements definition, solution development, quality testing, and implementation. These methods include waterfall, spiral development, prototyping, incremental and iterative development, rapid application development, and extreme programming (XP).

The waterfall method consists of stages with a precisely defined sequence, which must be completed before moving on to the next stage. In the first phase, system and software requirements are defined. The second phase establishes the software design. In the third phase, programmers write the code, the fourth phase is the testing phase (and integration if it is a complex system), the fifth phase includes implementation, training and documentation, and the sixth phase is software maintenance. Its main advantage is simplicity and ease of use, and its disadvantage is that it does not allow much thought or revision. When an application reaches the testing phase, it is complicated to go back and change something that was not well documented or thought out in the concept phase.

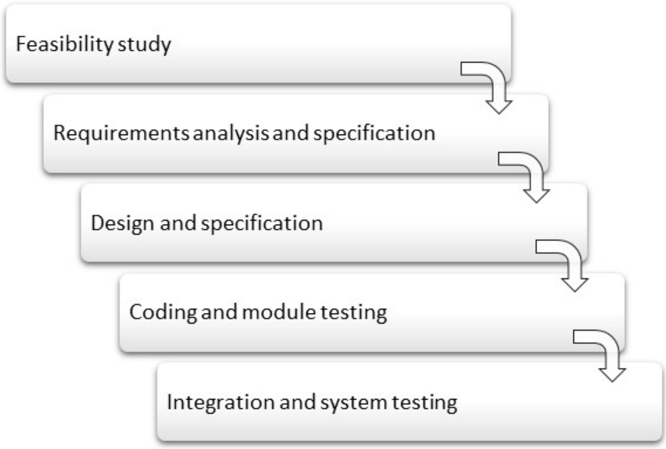


Figure 15. The waterfall method of software development

The spiral method consists of four phases: goal setting, risk assessment, development and quality control, and planning. The spiral method is used for large, complex projects. The progressive nature allows developers to break a large project into smaller pieces and tackle a single feature, ensuring nothing is missed. High costs, dependence on risk analysis, complexity, and complex time management could limit this method.

The Unified Process Method is a software development process that uses the UML (Unified Modeling Language) language to represent the model of the software system being developed. It is iterative, architecture-oriented, use-case-driven and risk-facing. It is based on expanding and refining the design through multiple iterations, with cyclical feedback and adaptation. The system is developed gradually over time, iteration by iteration, so this approach is also known as iterative and incremental software development. The iterations are divided into four phases,each consisting of one or more iterations: preparation, elaboration, construction, and transition.

Changing needs and market conditions have caused the emergence of agile software development methods. Agile methods have mostly the same characteristics:

- Specification, design, and implementation processes are intertwined. There is no detailed specification, and design documentation is automated or minimized.
- The system is developed through a series of versions, where users play a role in changing the next version. That's why agile methods are incremental, with small and fast increments.

Agile methods strive to achieve speed and resolve processes that are considered unnecessary. These methods include Extreme Programming (XP),

Scrum,Crystal, Adaptive Software Development (ASD), Dynamic System Development Method (DSDM), and Feature Driven Development (FDD).
XP (eXtremeProgramming) has short development cycles, incremental planning, constant feedback, reliance on communication and evolutionary design.
Scrum is an agile software development method that focuses on managing an iterative process rather than on individual technical approaches. Scrum is designed to work with small and agile teams of three to nine members led by a Scrum Master, who is responsible for ensuring that the team adheres to the rules and values of Scrum and interacts with people outside the team. He does not tell the team how to do their work; they decide it themselves. He only manages the process and gives general instructions.
The Scrum process is simple, and the so-called sprint is the central part that determines it. A sprint is a relatively short time frame of two to four weeks in which one increment of an iterative process is made. A sprint includes planning, daily Scrums, engineering work, reviews, and revisions. Daily Scrums are 15-minute daily meetings led by the Scrum Master, where they plan what should be done in the next 24 hours. The sprint review takes place at the very end of the sprint when what has been done is compared to what was planned, sometimes with the participation of potential product customers. A review (retrospection) allows the development team to express its opinion. This meeting happens after the review and before planning the next sprint.

Figure 16. Sprint is the scrum term for iteration[34]

The Crystal method focuses primarily on people and their interactions. Software development is treated as a game where everyone is encouraged to interact, be creative and generate ideas. The size of the development team defines the methods, which can be Clear (up to 6 people), Yellow (7-20 people), Orange (21-40 people), Red (41-80 people) and Maroon (over 80 people).
Adaptive Software Development (ASD) aims to enable teams to adapt efficiently to changing market demands or needs by developing products with light planning and continuous learning. Adaptability enables teams to align with organizational goals. The ASD approach encourages teams to develop through a three-phase process: speculate, collaborate, and learn. The benefits of ASD include end-user focus, which can lead to improved and more intuitive products,

enabling early delivery and encouraging greater transparency between developers and clients. Disadvantages of ASD are that it requires more user involvement, testing is integrated into each phase which increases project costs, and rapid iteration and continuous feedback that can slow down the process.
Dynamic System Development Method (DSDM) focuses on the entire product life cycle and consists of the following phases: feasibility study, business study, functional model iteration, design and development iteration, and implementation. Development participant roles vary from project to project and team to team and may include business architect, quality manager, system integrator, and many others.

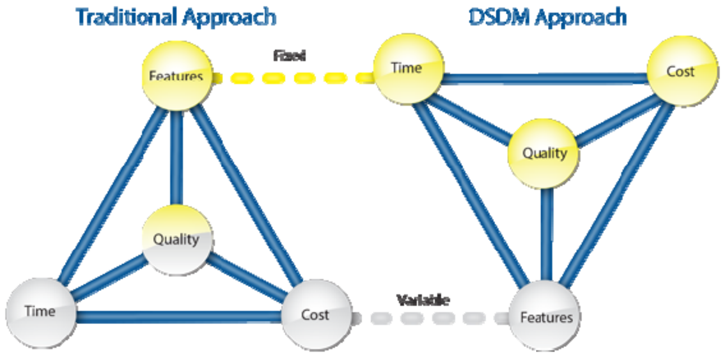


Figure 17. Dynamic System Development Method[35]

Feature Driven Development (FDD) is an iterative and incremental software development process. FDD brings together several industry-recognized best practices into a cohesive whole. These practices are driven from the perspective of features valued by clients. It consists of five main units: development of the overall model, construction of the list of features, planning by features, design of features, and construction of features. The characteristics (Features) mean different functionalities of the software. FDD gives the team an excellent understanding of the scope and context of the project. FDD also requires fewer meetings, unlike the Scrum method.
The Kanban Method, originating from just-in-time manufacturing, is a means to design, manage, and improve flow systems for knowledge work in software development [37]. The method allows organizations to start with their existing workflow and drive evolutionary changeby visualizing their workflow and limiting work in progress (WIP). Kanban systems use mechanisms such as a kanban board to visualize work and its process. Various Kanban boards are used: basic, advanced, and Heijunka boards [37].

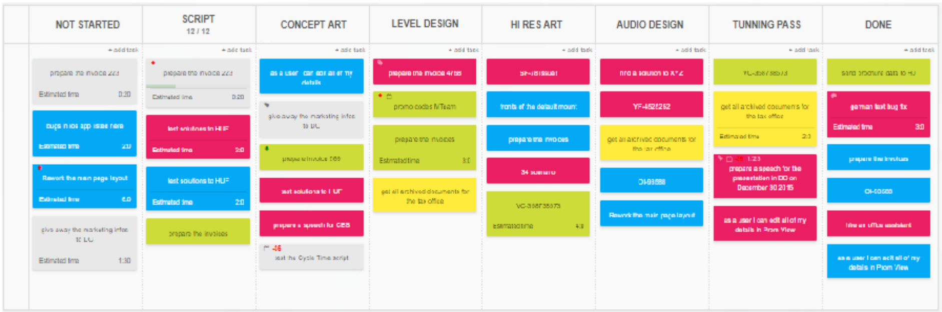


Figure 18. An example of a Heijunka boardfor the sequential software development process [37]

Agile software development techniques like Scrum or Kanban are not inherently different for desktop and IoT applications. Agile's fundamental principles and values remain the same regardless of the type of application being developed. However, there may be certain considerations and nuances specific to IoT applications that need to be considered when applying Agile practices, such as hardware dependencies, connectivity and network considerations, data processing and analytics, user experience and interface (UX/UI) design, and information security.

IoT applications often involve integration with hardware components and devices, introducing additional considerations regarding hardware compatibility, device communication protocols, and firmware updates. Agile teams developing IoT applications may need to coordinate closely with hardware teams and incorporate hardware testing and validation as part of their development process.

IoT applications rely on connectivity to communicate with devices and systems. Agile teams working on IoT applications must consider network reliability, latency, and security aspects related to data transmission and device communication. Testing connectivity scenarios and handling intermittent or unstable network conditions may be specific concerns for IoT development.

IoT applications generate vast data that must be processed, analyzed, and potentially integrated with other systems. Agile teams working on IoT applications may need to incorporate data analytics and processing capabilities in their development process, including Agile practices specific to data engineering, such as data pipeline development, data validation, and data quality assurance.

User interfaces for IoT applications often extend beyond traditional desktop interfaces. They may include mobile apps, web portals, or voice and gesture interfaces. Agile teams must consider the various user interface paradigms and design considerations specific to IoT applications, which may involve multidisciplinary collaboration with UX/UI designers and specialists in human-computer interaction.

IoT applications often handle sensitive data and are potential targets for security breaches. Agile teams developing IoT applications should prioritize security considerations from the outset, including secure authentication, data encryption, access control, and vulnerability management. Incorporating security testing and addressing security requirements as part of the Agile development process is crucial for IoT applications.

While the core Agile principles and practices remain consistent, the specific context and requirements of IoT applications may necessitate some adaptations and considerations in Agile implementation. Agile teams working on IoT projects should know these unique aspects and collaborate closely with stakeholders, hardware teams, data engineers, and security experts to ensure a successful Agile development process for IoT applications.

7. Conclusion

Software engineering provides the foundation for Industry 4.0 by developing the software systems and infrastructure required for automation, connectivity, data analysis, and cybersecurity. It enables the digital transformation of industries, driving efficiency, innovation, and new business models.

Software engineering provides the essential principles, methodologies, and practices that form the foundation of Industry 4.0. It enables the development of reliable, scalable, and secure software systems that drive automation, connectivity, and data-driven decision-making in various industries. By leveraging software engineering expertise, organizations can successfully embark on their Industry 4.0 journey and unlock the benefits of digital transformation.

The interdisciplinary nature of software engineering reflects the complexity and diversity of challenges faced in developing software systems. Collaboration across disciplines brings together different perspectives, expertise, and approaches, leading to the development of robust, innovative, and effective software solutions. Software engineers must be open to learning from various fields and working collaboratively to address the multifaceted aspects of software development.

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Implementation of Industry 4.0 in the Manufacturing Industry: A Bibliometric Approach

Gordana Zeba[*1], Mirjana Čičak[2]

Abstract: *Industry 4.0 represents the integration of advanced technologies into manufacturing processes with the goal of improving efficiency, productivity and decision-making. However, despite the significant technological opportunities offered by Industry 4.0, there remains a significant gap between these opportunities and their practical implementation in the manufacturing industry. This gap poses a challenge to effectively reaping the benefits of Industry 4.0 and underscores the need for further research and bridging this gap between the technology and its practical application. This study presents a comprehensive analysis of the relevant literature addressing the implementation of Industry 4.0 technologies in manufacturing using a bibliometric approach based on data from the Web of Science Core Collection citation databases. The analysis includes quantitative methods such as direct citation analysis, keyword co-occurrence analysis, co-citation networks, and bibliographic coupling. The aim is to capture the dynamics of published research on the implementation of Industry 4.0, to investigate the intellectual and conceptual structure, and to identify key collaborative research networks. The results contribute to a deeper understanding of the current state and progress of research in this area. The study highlights the importance of continued research, collaboration, and strategic planning to fully realize the benefits of Industry 4.0 technologies in the manufacturing industry.*

Keywords: *Industry 4.0 implementation, Enabling technologies, Manufacturing industry, Bibliometric analysis*

1. Introduction

The term Industry 4.0 was first used in 2011 at the Hannover Messe Industrie trade fair, where it was shown how cyber-physical systems can bring about a paradigm shift in industrial automation [1]. One of the prominent elements of Industry 4.0 in the manufacturing industry is the concept of the smart factory. Smart factories use technologies such as the Internet of Things (IoT), artificial intelligence (AI), Big Data analytics, and robotics to create highly connected and autonomous manufacturing systems [2]. In a smart factory, machines, devices, systems, and people communicate with each other in real-time, enabling

[*1,2]Mechanical Engineering Faculty, University of Slavonski Brod
E-mail: gzeba@unisb.hr

efficient information sharing and collaborative decision-making. This connectivity enables manufacturers to monitor and control their operations more effectively, optimize workflows, and respond quickly to changing demands or disruptions [3]. Industry 4.0 enabling technologies offer great opportunities to improve automation, flexibility, productivity, and efficiency in the industry [4], [5-7], namely the Industrial Internet of Things (IIoT), cloud computing, Big Data analytics, autonomous robots, simulations/digital twins, additive manufacturing (e.g., 3D printing), augmented reality, cybersecurity, and horizontal and vertical system integration [3], [8, 9]. The transition to Industry 4.0 can have troubling and destabilizing effects, pose significant competitive challenges, and raise legitimate security concerns [10]. Industry 4.0 affects all areas of life and work, in addition to the industrial sector, and has a significant impact on living standards, which is why the topic of Industry 4.0 is attracting a great deal of interest in both academic circles and companies [1], [7].

Previous research has mainly focused on the manufacturing sector when examining the impact of Industry 4.0 [11]. This is understandable, as manufacturing plays a key role in the world's economies and contributes to economic growth. [12, 13]. Today’s manufacturing industry is very diverse and includes various sectors such as automotive, aerospace, electronics, pharmaceuticals, consumer goods, etc. Production in the context of Industry 4.0 is undergoing significant change due to digitalization and the integration of advanced technologies. It continues to evolve rapidly, driven by technological advances, market dynamics, and changing customer expectations.

Manufacturing companies face a challenging manufacturing environment due to globalization, personalization, and market saturation, which translates into increasing quality requirements, shorter product life cycles, and pressure to reduce the cost of manufacturing processes across the value chain [14, 15]. With an increasing focus on innovation, sustainability, and digitalization, manufacturers are striving to remain agile, competitive, and adaptable in a rapidly evolving global environment. However, there are six central design principles for implementing Industry 4.0: interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity [16] [17]. Manufacturing is one of the important sectors that can gain significant benefits by adopting the principles and technologies of Industry 4.0 [4].The expected benefits for production depend on the degree of implementation of Industry 4.0 technologies, with the following benefits most frequently cited: increased productivity, improved product quality, increased flexibility (fluctuating customer requirements, customized products), shortening of the production cycle, energy efficiency, decreased production costs [18][19]. In order to realize these benefits and survive in the market, manufacturers are forced to implement the technologies and principles of Industry 4.0, and in recent years companies are increasingly using technologies related to the concept of Industry 4.0 [20-22]. The transition to Industry 4.0 is a complex and multi-layered process that involves not only technological advances but also strategic considerations. The manufacturing industry is investing more than any other industry in the implementation of Industry 4.0 [23]. The implementation of Industry 4.0 is leading to structural changes in the technological base of manufacturing in countries around the world, such as China, the United States, and European countries, as stronger economies in developed countries invest more in Industry 4.0 [24]. For the successful implementation of Industry 4.0, it is necessary to carry out specific and concrete activities [25], and according to the article [26] digitalization serves as the primary approach to facilitate the implementation of Industry 4.0.

Industry 4.0 technologies are more likely to be adopted by large enterprises, while medium and small enterprises struggle to implement them in production, especially in developing countries [27][28]. On average, less than 20% of large companies are successful in their digital transformation efforts, and the situation is even more difficult for small and medium-sized enterprises (SMEs) [26][29]. Consequently, the transition of manufacturing to Industry 4.0 varies from country to country and is slow, with different challenges and problems [19]. One major problem is the standardization of existing production systems [30]. Since there is no standard definition of Industry 4.0 in the literature [23][31], it is understandable that there are also no standard implementation models [7]. The implementation of Industry 4.0 technologies is a major challenge for many companies because there is no systematic and comprehensive frameworkand models for implementation [32][33].

While there are general guidelines in the literature for implementing Industry 4.0 technologies and transforming manufacturing into a smart factory [34][35], implementation models are less common. The concepts of smart factories, sustainable production, and lean manufacturing in the context of Industry 4.0 are explored in the literature. The literature discusses various aspects of Industry 4.0 basic technologies, concepts, barriers, and opportunities related to Industry 4.0 implementation [36], and maturity and readiness models as key tools for companies to effectively implement Industry 4.0 principles and practices [24]. According to [37], the level of implementation of enabling technologies such as the Internet of Things, cybersecurity systems, and Big Data can be considered very high; Cloud computing, artificial intelligence, simulation, and machine learning can be considered high; the implementation level of intelligent robots, virtual reality, augmented reality, blockchain, cybersecurity, and additive manufacturing can be classified as moderate; and the degree of implementation of digital twins, quantum computing, and edge computing, on the other hand, can be classified as very low.

However, a review of the literature shows that research on implementation models of Industry 4.0 technologies is insufficient. Therefore, this study conducted a comprehensive literature review using bibliometric methods to capture the intellectual, conceptual, and social structure of the research field on the implementation of Industry 4.0 technologies in the manufacturing sector. Although there are articles in the literature on the implementation of Industry 4.0 using a bibliometric approach, it only addresses the implementation of individual technologies, not a comprehensive approach. The bibliometric analysis was performed using software VOSviewer because there is a large number of publications on Industry 4.0 and this number is growing exponentially [38], and it would be difficult to perform the analysis in a conventional way.

There is no doubt that the field of Industry 4.0 is in a constant process of development, which requires continuous monitoring of progress in research [39]. Accordingly, the aim of this study is to describe the current state and progress of research in the implementation of Industry 4.0 in the manufacturing sector and to identify and visualize the conceptual and intellectual structure and the structure of the collaborative network. According to the stated objective of the research, the following research questions (RQ) were defined: RQ1 - What is the trend in publishing articles on the implementation of Industry 4.0 in the manufacturing industry?; RQ2 - Which countries contribute most to research on the implementation of Industry 4.0 in the manufacturing industry in terms of publishing articles and number of citations?; RQ3 - In which research areas are there the most articles on the implementation of Industry 4.0?; RQ4 - Which are the most cited authors, publications and sources in the area of implementing Industry 4.0 in the manufacturing industry?; RQ5 - What is the intellectual and conceptual structure of research on the implementation of Industry 4.0?; RQ6 - How has the research focus in the area of implementing Industry 4.0 in production evolved over time?; RQ7 - What is the macro-level structure of the cooperation network?

The remainder of this article is organized as follows. The second section describes the research methodology. The third section contains the results, followed by related discussion in fourth section. The fifth section provides a conclusion.

2. Research Methodology

In this research, bibliometric analysis was used to reveal the dynamics of published research on the implementation of Industry 4.0 technologies, the intellectual and conceptual structure, and the main collaborative research networks. Bibliometric analysis as a quantitative method is applied to avoid the subjective interpretation of researchers, and the application of these methods is widely used in various research fields because bibliometrics provides a more objective and reliable analysis than other methods [40]. The results of the bibliometric analysis are based on quantitative analysis of citations among published papers, which provides an objective representation of the real situation and identification of the most important research topics [41]. Bibliometric analysis also has some disadvantages, such as the impossibility of long-term predictions [42][43]. Bibliometric tools such as direct citation analysis, keyword co-occurrence analysis, co-citation networks, and bibliographic linkage have been used to identify existing research directions and potential directions for future research.

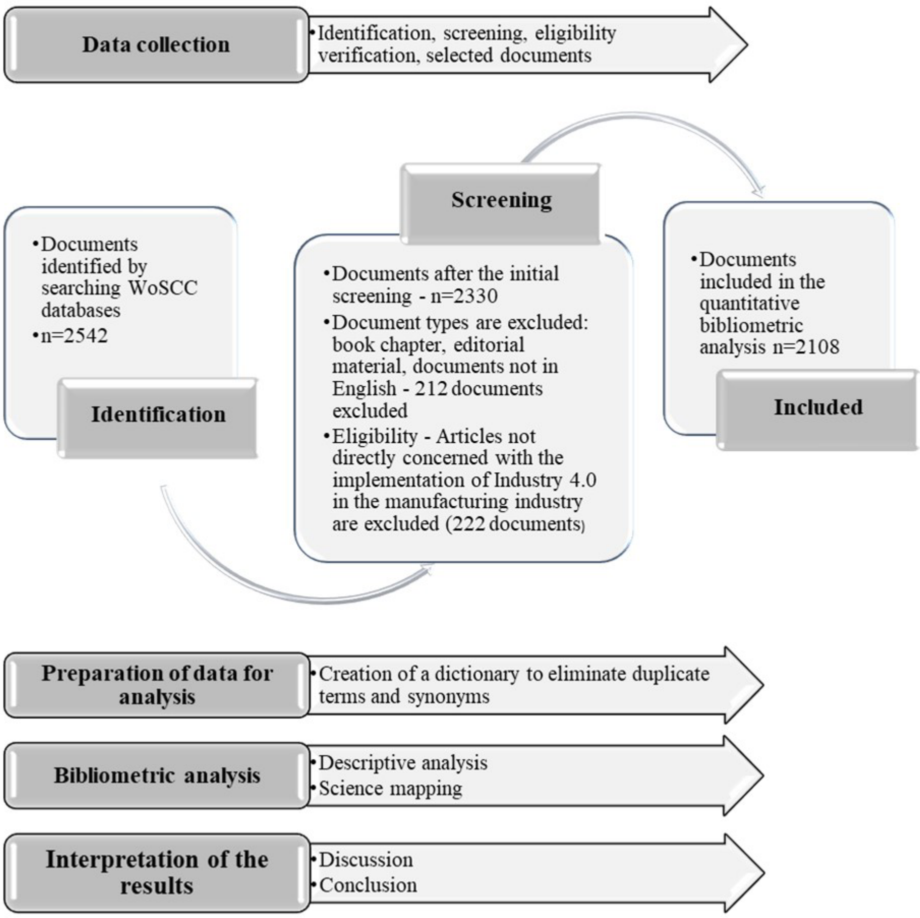

Figure 1. Research methodology

The study was conducted in four phases according to the methodology shown in Figure 1. In the first phase, data were collected from the Web of Science Core Collection citation databases. The PRISMA methodology was used to ensure the quality of data collection and the possibility of replicating the process [44]. The search covered a 10-year period (from 2013 to 2018), and three criteria were used to define the query. The first criterion was related to Industry 4.0, selecting keywords related to Industry 4.0, including the names of several countries' strategies: ''Industry 4.0'', ''Advanced Manufacturing Partnership'', ''Industrial Value-Chain Initiative'', ''Made in China 2025'', ''Future of Manufacturing'', ''Smart Manufacturing'', ''Initiative Industry 4.0'' [45]. The second criterion refers to the implementation of Industry 4.0, using keywords such as ''implement*'', ''model'', ''framework'', ''roadmap'' and ''strateg*''. The research focuses on the manufacturing industry, and the third criterion was defined by the keywords ''manufacturing'', ''production'' and ''manufacturing industry''. Based on the established criteria, a search of the Web of Science Core Collection citation database was conducted with a defined query: (TS=(''Industry 4.0'' OR ''Advanced Manufacturing Partnership'' OR ''Industrial Value-Chain Initiative'' OR ''Made in China 2025'' OR ''Future of Manufacturing'' OR ''Smart Manufacturing'' OR ''Initiative Industry 4.0'') AND TS=(implement* AND (model OR framework OR roadmap OR strateg*)) AND TS=(manufacturing OR production OR ''manufacturing industry'')) .

In the identification phase, 2,542 results were obtained. The sample included only scientific papers, review papers, and conference papers in English. Documents in the form of book chapters, editorial material, and papers in languages other than English were excluded from the collected set of documents. Documents published outside the period from 01/01/2013 to 12/31/2022 were also excluded. This period was chosen in view of the publication of Industry 4.0 initiative and the German economic development strategy in 2013. Screening of the documents when preparing the data for analysis based on the previously described limitations, which are in line with the research objectives and research questions, yielded 2330 results. In the acceptance screening phase, the titles and abstracts of the documents were screened and only papers dealing with models, strategies, and implementation options of Industry 4.0 in the manufacturing industry were selected. In this way, a total of 2108 documents were included in the bibliometric analysis to obtain answers to the research questions. These scientific papers represent the knowledge base (intellectual basis) for the field of Industry 4.0 implementation in the manufacturing industry.

The data were then prepared for bibliometric analysis. The data were cleaned, i.e., a dictionary was created to remove duplicates, i.e., synonyms of terms. In the next phase of the study, bibliometric analysis was performed, namely descriptive bibliometric analysis and science mapping (in which co-occurrence analysis of keywords, citation analysis, co-citation analysis, bibliographic coupling, and social network analysis were performed) to identify the main research topics on the implementation of Industry 4.0 technologies and future research areas, i.e., intellectual structure and research fronts, and collaborative networks at the macro (country) level. VOSviewer software, version 1.6.19 [46], was used as a tool to perform the analysis. VOSviewer is widely used in the scientific community for bibliometric analysis and facilitates the analysis of a large number of publications given the sudden increase in published research. For all types of analyses, data were normalized using a similarity measure called strength of association.In the final stage, the results were analyzed and conclusions were drawn.

3.Bibliometric Analysis

3.1. Descriptive bibliometric analysis

To answer research question RQ1, a descriptive bibliometric analysis was conducted. This analysis includes an analysis of the trend of increase in the number of articles published, an analysis of the greatest contribution to research in the field of Industry 4.0 implementation in terms of number of publications and citations by country, and which are the most influential publications, authors, and sources. Descriptive analysis provides valuable insight into the performance of authors, institutions, or countries in the field. It helps identify publication trends, determine the most prolific and influential authors, identify the most cited publications, identify the most cited sources, and identify the countries with the highest research performance.
Figure 2 shows the trend of the increase in the number of publications on the implementation of Industry 4.0 from the beginning of 2013 to the end of 2022.

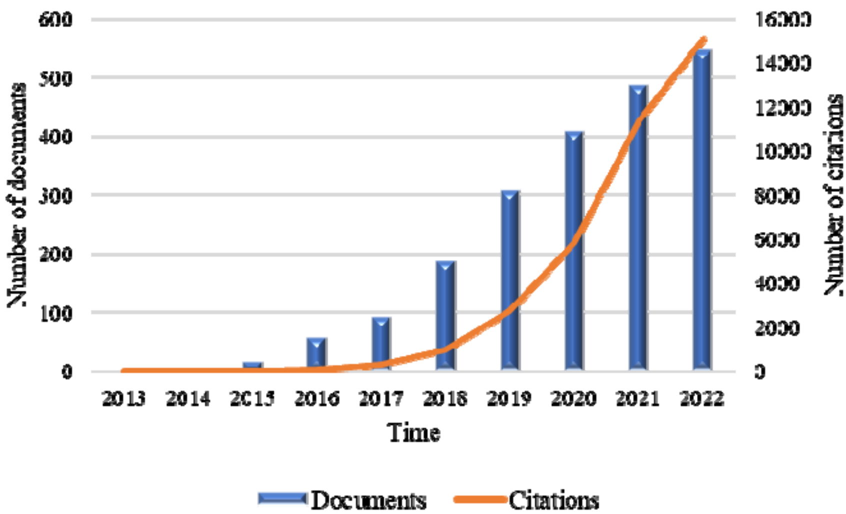

Figure 2. Number of published papers and citations by year, period 2013 - 2022

A steady increase in the number of publications has been observed since 2015, and a stronger increase in the number of publications and number of citations begins in 2018, and this growth trend is maintained until the end of 2022. This shows the growing interest of researchers in research on the implementation of Industry 4.0 in the manufacturing industry.
Figure 3 shows the productivity of different countries in the field of research on the implementation of Industry 4.0 in production (the graph was created in the Microsoft Excel application) as the answer to RQ2. The most productive countries (with more than 100 published papers) are China with 261 papers, Italy with 226 papers, and Germany with 209 papers. They are followed by the United States with 188 publications and India with 186 publications. The United Kingdom, Brazil, France and Spain have published between 135 and 104 papers. Of the countries that have published research on the implementation of Industry 4.0, more than 65% are European countries. Europe is at the forefront of the implementation of Industry 4.0 technologies research. Countries such as Italy, Germany (which initiated the concept of Industry 4.0), United Kingdom and France contributed significantly to the literature on this topic.

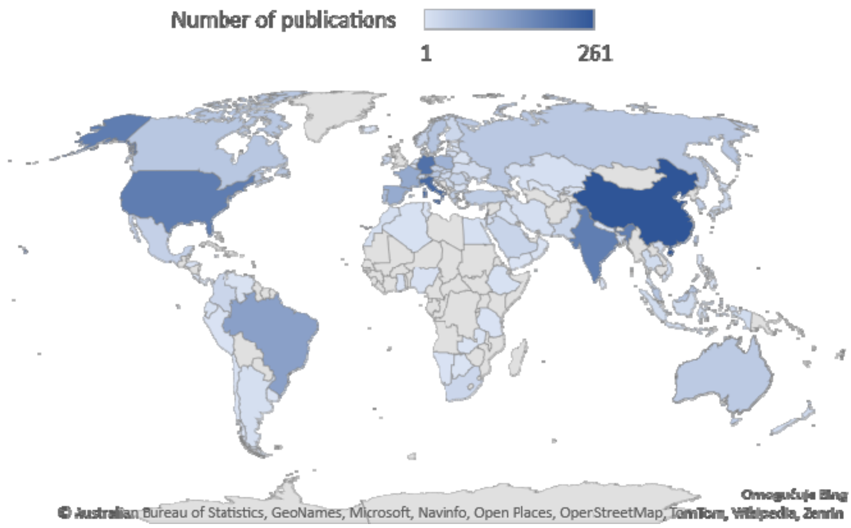

Figure 3.Global distribution of the number of publications on the implementation of Industry 4.0

As answer to RQ3 Figure 4 shows the scientific fields to which the papers from the research sample on the implementation of Industry 4.0 in production can be assigned, based on analytical tools of WoS. The graph shows the research areas to which at least 40 published papers belong. Most of the papers belong to the scientific fields of engineering (1268 papers) and computer science (696 papers),which is understandable since they deal with production and information technologies. In the other scientific fields, there are less than 300 published papers on the implementation of Industry 4.0 in manufacturing for the observed period.

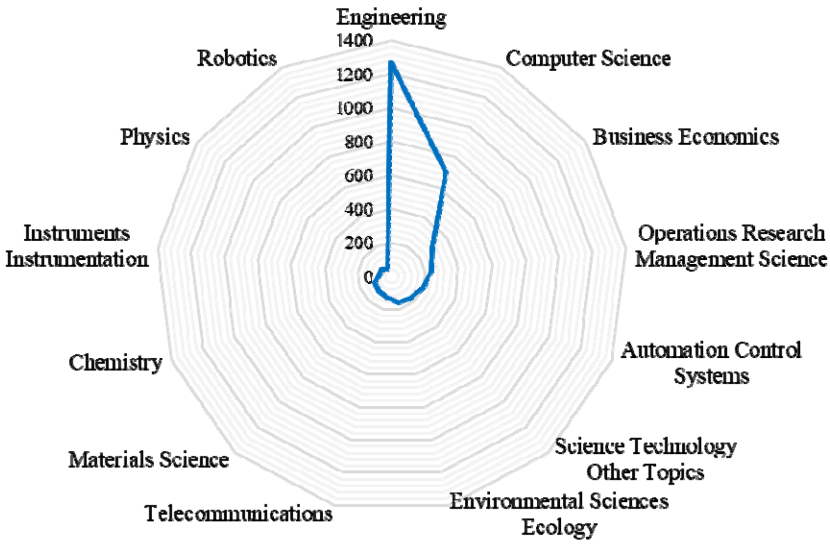

Figure 4. The most represented research areas

Figure 5 shows that most publications relate to manufacturing (26,14%) and industrial engineering (21,96%) (the categories are defined in the Web of Science platform).

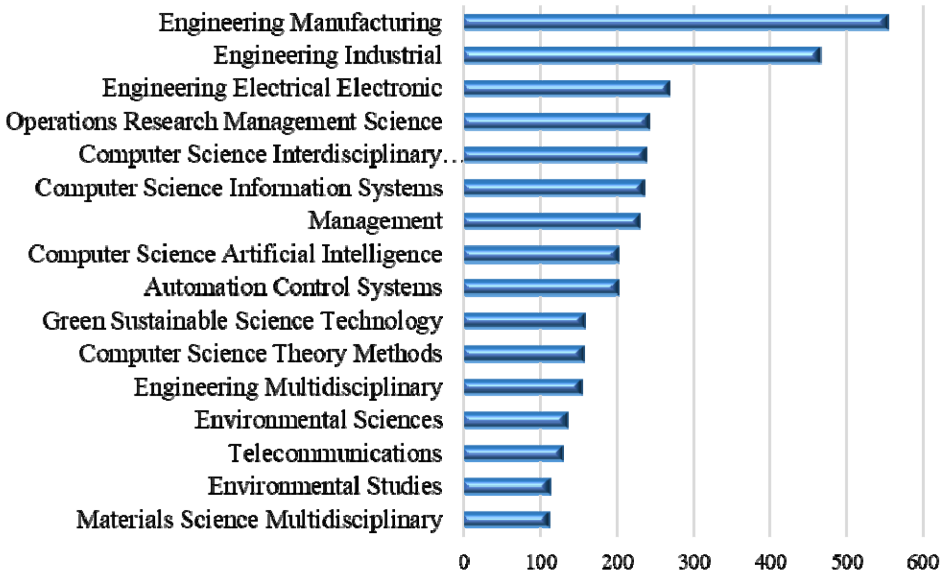

Figure 5.Web of Science categories

The most influential authors, articles and sources, based on the number of citations, were identified by citation analysis, in order to obtain an answer to RQ4. The analysis was performed using VOSviewer software, and the criterion for authors was that the authors had at least 5 publications in the research area and their papers had at least 100 citations. Of the total 6646 authors, 43 authors met this criterion, of which the 10 most influential are listed in Table 1 by number of citations.

Table 1. The most influential authors, based on the number of citations

Authors	Articles	Citations	Total Link Strength
Ayala, Nestor Fabian	5	1635	95
Ghobakhloo, Morteza	10	859	111
Xu, Xun	11	859	51
Pellerin, Robert	6	856	69
Lamouri, Samir	5	854	60
Tao, Fei	8	831	21
Li, Di	6	810	21
Sihn, Wilfried	5	809	39
Tortorella, Guilherme Luz	8	660	70
Zheng, Pai	6	621	36

It is noteworthy that Ayala Nestor Fabian emerges as the most influential author based on the number of citations in the field of Industry 4.0 implementation in the manufacturing industry. This suggests that Ayala's research and contributions have garnered significant attention and recognition within the research community. The most cited article by Ayala, Nestor Fabian in the Web of Science Core Collection, as of 2019, is ‘’Industry 4.0 technologies: Implementation patterns in manufacturing companies’’ [47]. This particular work likely represents a seminal contribution by Ayala, providing valuable insights and analysis on the implementation patterns of Industry 4.0 technologies in manufacturing companies. Ayala’s work ranks eighth in the number of articles published. The second place of Ayala in total number of links indicates a strong connection to other authors in the field and shows how important these citations are.

It is notable that GhobakhlooMorteza holds a significant position in the citation analysis. Ranking second in terms of both the number of citations and the number of articles published suggests that his work has made a substantial impact and has been influential in the field of Industry 4.0 implementation in the manufacturing industry.

Furthermore, having the highest total link strength indicates that GhobakhlooMorteza is highly connected to other authors through citations. This implies that his research has been extensively referenced and acknowledged by other scholars, establishing strong connections and collaborations within the research community.

These findings highlight GhobakhlooMortezas contributions and influence in the field, suggesting his work has significantly influenced and contributed to the body of knowledge on Industry 4.0 implementation in the manufacturing industry.

Table 2 shows the most influential articles by number of citations. The most influential article is above mentioned [47] with the largest number of citations and also the largest number of links.

Table 2. The most influential articles, based on the number of citations

Document	Citations	Links
Frank (2019) [47]	868	7
Wang (2016) [48]	682	4
Dalenogare (2018) [49]	678	7
Kusiak (2018) [50]	562	1
Schumacher (2016) [51]	557	5
Ghobakhloo (2018) [52]	508	5

Table 3 shows the results of a citation analysis conducted to identify the most relevant sources for research on the implementation of Industry 4.0 in the manufacturing industry. The citations analysis in VOS viewer focused on sources that had published at least 10 articles in the field and received at least 1000 citations. Of the 843 sources examined, 10 journals met these criteria.

Table 3. The most influential sources, based on the number of citations

Source	Number of articles	Number of citations	Total link strength
International Journal of Production Economics	21	2537	229
International Journal of Production Research	32	2406	233
Technological Forecasting and Social Change	19	2206	179
Sustainability	87	2012	270
Computers in Industry	29	1640	125
Journal of Manufacturing Technology Management	34	1451	228
Journal of Manufacturing Systems	38	1444	115
Computers & Industrial Engineering	39	1319	117
IEEE Access	35	1147	59
Journal of Cleaner Production	25	1095	157

The Table 3 also lists the strongest links between sources, based on the total link strength. The presence of strong links, as indicated by the total link strength between sources, suggests that these specific sources tend to cite other sources more frequently. This implies a higher level of interconnectivity and scholarly referencing among these journals within the field of Industry 4.0 implementation in the manufacturing industry. Such strong links indicate that these journals are influential in shaping the discourse and knowledge dissemination within the research community, as they reference and build upon the work published in other journals.The International Journal of Production Economics is the most cited journal, but it is not the most productive in terms of the number of articles published, and it does not have the highest total link strength. The most productive journal is Sustainability, which also has the highest total link strength and ranks fourth in terms of number of citations. The journals International Journal of Production Research and Technological Forecasting and Social Change are second and third, respectively, in terms of number of citations.
Overall, the results of this citation analysis provide valuable insight into the influential sources and their relationships to one another in the field of Industry 4.0 implementation in the manufacturing industry.

3.2. Science mapping

Insight into the intellectual and conceptual structure of the research is important to identify key concepts, theories, and frameworks that form the foundation of the research area and to identify areas that have not been adequately explored.

Analyzing the intellectual and conceptual structure of research allows for the discovery of various themes within the research field, the identification of research trends, and current topics in which researchers are showing great interest. In this study, the methods of co-citation analysis and bibliographic coupling were used to identify the intellectual structure and research fronts of research on the implementation of Industry 4.0 technologies, and keyword co-occurrence analysis was used to reveal the conceptual structure. Co-authorship analysis was used to reveal the social network structure, specifically to identify the macro-level international collaborative network.

3.2.1. Intellectual structure of research domain

A.Intellectual base of research

For the purposes of this study, and to answer question RQ5, a co-citation analysis of documents was chosen, the goal of which was to determine the intellectual knowledge base of the research area. In co-citation analysis, the degree of similarity between two documents depends on the number of documents that cite both works. Co-citation analysis provides a simple way to evaluate the relationship between research articles. When two articles are co-cited in the same publication, it indicates a mutual relationship between them. The frequency of co-citations serves as an indicator of similarity between articles, as it indicates how often they are cited together. From the frequency of co-citations, it can be concluded that two articles refer to the same research area [53]. In essence, joint citations provide a link that highlights the interconnectedness and common focus of articles within a given field. In the VOSviewer software, a total of 74196 cited references were identified in the sample of WoSCC. A threshold of at least 20 cited references was chosen, reducing the sample to 286 cited references for the co-citation analysis. The fractal counting method and the number of citations were chosen as the measure for visual representation, and the threshold for the minimum cluster size was set to 5 cited references. Figure 6 shows the network of cited references connected in clusters, i.e., five clusters within the knowledge base: A) red cluster (total 112 cited references) - Digital Transformation in Manufacturing; B) green cluster (total 79 cited references) - Integration of Industry 4.0 Technologies in Manufacturing; C) blue cluster (total 49 cited references) - Enabling Industry 4.0: technologies, systems and strategic implementation; D) yellow cluster (total of 26 cited references) - Technology of digital twins in smart manufacturing; E) purple cluster (total of 20 cited references) - The concept of lean manufacturing in Industry 4.0. It can be seen that the most thematically connected red and blue thematic units.

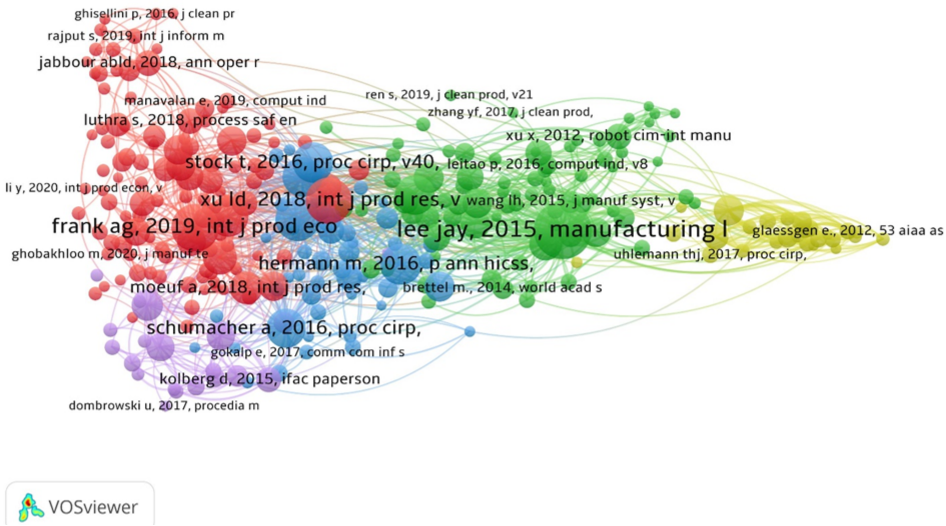

Figure 6. Visualization of the network of cited references - result of co-citation analysis (VOSviewer software)

The red cluster, which contains 112 cited references, refers to digital transformation in manufacturing. Digital transformation means the introduction and integration of digital technologies and processes in manufacturing. It includes digitalization, the use of new technologies, and the transformation of traditional manufacturing into advanced manufacturing systems [47]. It includes concepts such as cyber-physical systems, the Internet of Things (IoT), cloud computing, blockchain technology and other enabling and emerging technologies [54]. It focuses on improving manufacturing performance, industrial integration, interoperability, and enterprise architecture. These concepts and issues are relevant not only in developed countries but also in developing countries, where adopting the principles of Industry 4.0 can promote industrial growth and development [55].

The focus of the green cluster, which contains 79 cited references, is on integrating the enabling technologies and concepts of Industry 4.0 in the manufacturing industry. A prominent aspect of this cluster is cyber-physical systems, which represent the integration of physical and digital components in production processes. This includes the use of sensors, actuators and communication networks that enable real-time monitoring, control and optimization of manufacturing processes. The importance of connectivity, automation, and real-time information exchange to optimize production, improve operational efficiency, and drive innovation has been highlighted. In addition, this cluster emphasizes the importance of sustainability, product lifecycle management, and service orientation in manufacturing.

The blue cluster, which includes 49 cited references, represents comprehensive research on past, present, and future aspects of Industry 4.0, with the goal of thoroughly understanding the current state of knowledge and identifying future research directions in the field [56-59]. In addition, the topic unit addresses the assessment of readiness and maturity of manufacturing companies for Industry 4.0 by developing a maturity model. Such models make it possible to assess the readiness and progress of organizations in adopting Industry 4.0 practices and technologies [51].

The yellow cluster contains a total of 26 cited references, including research on the integration of digital twin technology and the concept of smart manufacturing, and the use of digital twin models to create virtual representations of physical products, processes, and systems in the manufacturing industry. The focus is on the convergence of digital and physical domains for data exchange and communication between virtual and real manufacturing environments [60][61][62][63]. The topic highlights the importance of standardization and interoperability in the implementation of digital twin solutions and smart manufacturing [64].

There are a total of 20 cited references in the purple cluster, and the research focuses on integrating advanced technologies, such as cyber-physical systems and the Internet of Things (IoT), with lean manufacturing principles to promote operational efficiency, productivity, and performance improvement. Lean manufacturing is now considered the most important manufacturing paradigm [65]. The integration of lean manufacturing principles aims to increase productivity and reduce costs in manufacturing organizations [66]. The subject area includes the exploration of concepts and technologies in various contexts, including developing countries.

B. Research Fronts

Research fronts represent the most cited papers of the five-year period, clustered to provide insight into current research priorities and to indicate future research directions [67][68][69]. The bibliographic coupling method was used to identify research fronts. Research results of [70][71] have shown that the bibliographic matching method reveals research fronts more accurately than the co-citation analysis.Bibliographic coupling is a method that provides insight into research trends, research groups, and the dissemination of knowledge within a research field by identifying links between scientific papers based on their citation relationships. It is used to assess the similarity and relatedness of scientific publications based on their common citations. Analyses the citation patterns of articles and determines the degree of overlap between their reference lists. Publications that cite similar works are considered bibliographically related and are assumed to share thematic or conceptual similarities.

The bibliographic coupling analysis was performed for the five-year period from 2018 to 2022. The unit of analysis is a document and only documents with at least 20 citations are included in the analysis, resulting in a sample of 413 scientific articles. In the VOSviewer software, it is specified that 75% of the articles are included in the analysis. As a result, four clusters were formed, which are shown in Figure 7. The names of the research fronts (topics) were determined based on a review of keywords, article titles, and abstracts: A) Red cluster: Smart Manufacturing and Industry 4.0 Technologies Integration; B) Green cluster: Digital Transformation and Business Models; C) Blue cluster: Sustainable Manufacturing and Integration; D) Yellow cluster: Lean Manufacturing and SMEs.

The red cluster includes 179 articles, and research is focused on advancing smart manufacturing. Here, the integration of smart systems such as cyber-physical systems, digital twins, internet of things, big data and blockchain technology is studied to optimize production processes, increase efficiency and minimize environmental impact [72], [73]. Research within this cluster aims to leverage innovative solutions to drive the evolution of manufacturing towards smarter and more technologically advanced processes [52].

The Green Cluster (129 articles) addresses digital transformation in manufacturing [47][49] and explores its profound impact on business models and practices, with a focus on business model innovation for small and medium-sized enterprises (SMEs) [74].It examines the challenges, opportunities, and performance aspects associated with the adoption of digital technologies and explores how they are shaping the future of manufacturing companies and economies [75]. By analyzing the transformative potential of digital change, this cluster aims to facilitate the successful integration of new digital paradigms into manufacturing companies.

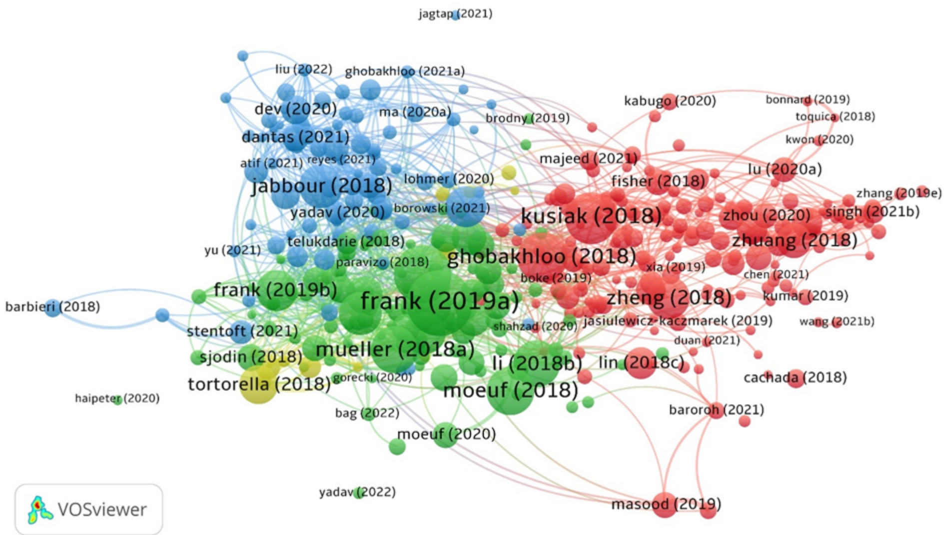

Figure 7.Network visualization of research fronts

The Blue Cluster includes 88 articles and focuses on sustainable manufacturing practices and their integration into the overall operations and supply chains of manufacturing companies. It examines environmental sustainability, circular economy principles, and sustainable supply chain management. By focusing on environmentally sound practices and integrating sustainability principles, this cluster aims to promote long-term profitability and environmental protection in the manufacturing industry [76-78].

The yellow cluster includes 13 papers that address the implementation of lean manufacturing principles in the context of Industry 4.0 [79][80]. This cluster highlights the importance of lean practices for SMEs to thrive and contribute to the overall development of national economies.

Figure 8 shows a map visualizing the density of research fronts based on citation weights. Using a visual representation of network density, it is easy to identify areas of higher density where the network nodes are close together, indicating the most important areas of the network.The greater the number of items in the neighbourhood and the higher the weighting of these elements, the closer the colour of the point is to red. The assumption is made that the research on a particular topic is considered more mature and developed when the density of the corresponding research front is higher [81].

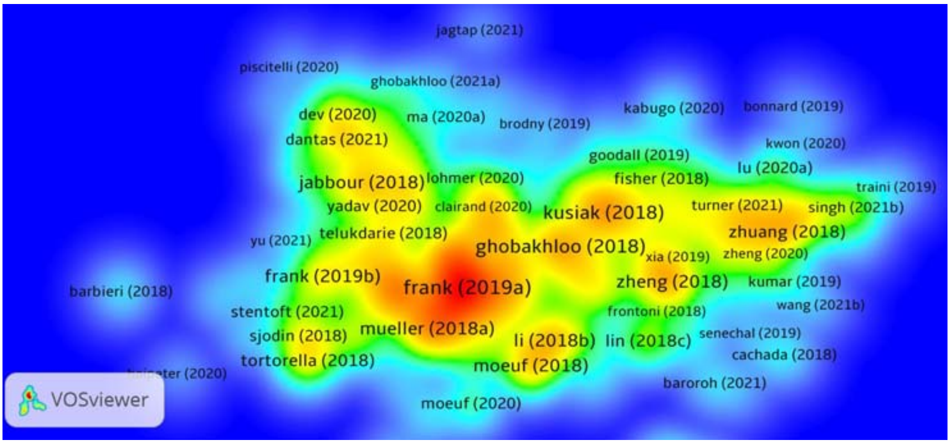

Figure 8. Density visualization of research fronts

In Figure 8, a more intense red colour indicates a higher research density. From the network density visualization, the highest research density is in the area of adoption of Industry 4.0 technologies in manufacturing companies and the associated challenges such as technological complexity, organizational change, workforce skill requirements, and infrastructural constraints. Understanding these challenges can help develop strategies and best practices to overcome them and ensure successful implementation. There is a particular focus on researching strategies that enable small and medium-sized enterprises to effectively use Industry 4.0 technologies and overcome resource constraints. There are some other research areas with a somewhat weaker intensity of red in the density indicator, such asthe integration of Industry 4.0 technologies and environmentally sustainable manufacturing and on the critical success factors of integration; research on digital twins in the context of manufacturing; the opportunities and challenges of adopting and using advanced technologies to promote innovation and efficiency in manufacturing, synergies between sustainable supply chain management, enterprise resource planning, and the potential of Industry 4.0 technologies to promote sustainability and efficiency in supply chain operations. Areas highlighted in green represent marginal research on a particular implementation topic in the context of the manufacturing industry. Research in the areas highlighted in blue, which are older, has no potential for development. Newer researches that are still in the blue highlighted areas are potential new topics that will be developed in the near future, such as research on human-robot collaboration, energy sustainability, human-centered approaches in the context of Industry 4.0, and the future vision of Industry 5.0 to balance technological advancement and human well-being.

The weakness of the dark red areas in the visual representation of density indicates that there is still much room for research on the topic of implementing Industry 4.0 technologies in the manufacturing industry.

3.2.2. Conceptual structure

To establish the conceptual structure of the research about implementation Industry 4.0 technologies in manufacturing, the co-occurrence analysis of terms that occur most frequently in publication was used. The co-occurrence analysis was performed using the VOSviewer software.

Of the total 6248 terms, the terms that occurred at least 10 times were selected for analysis. This reduced the sample for analysis to 161 terms. The default cluster size is set to a minimum of 5 terms in a cluster. The result of the analysis was 4 clusters.The co-occurrence analysis revealed four dominant themes and emerging trends in the field: Cluster 1 (red) - Technology-Driven Transformation; Cluster 2 (green) - Smart Manufacturing and Process Optimization; Cluster 3 (blue) - Industry 4.0 Technologies and Integration; Cluster 4 (yellow) - Technology Adoption and Integration Management.

Figure 9 shows the network visualization of the co-occurrence analysis and Table 2 shows the 30% most common terms from each cluster.

Cluster 1 (red) contains 50 terms covering different aspects and dimensions of this topic. The analysis of the mentioned keywords shows a thematic context covering technology, sustainability and business transformation in the context of manufacturing and supply chain management.

Digital transformation as one of the main themes illustrates the comprehensive process in which organizations adapt to technological change, digitize their business, and transform their operational processes to become more competitive and innovative [82][83]. Supply chain management and sustainability are key elements in today's business environment [84]. Companies are increasingly recognizing the importance of sustainable practices and responsible supply chain management to reduce their environmental impact, including reducing waste, optimizing resources, and promoting circular economy principles [85]. Sustainability also refers to the harmonization of economic, environmental, and social aspects of a business to achieve long-term success [86]. There is a growing interest in integrating the principles of lean manufacturing, which aim to eliminate waste, optimize resources, and improve operational efficiency in the production process, and Industry 4.0 technology [87].Innovation and technology are the main drivers of development in this area. Innovation is key to increasing competitive advantage and ensuring the long-term success of companies in a dynamic business environment [88]. Quality management, productivity, knowledge and skills management, as well as data analytics and predictive analytics also play an important role in achieving excellence in manufacturing and supply chain management [89].

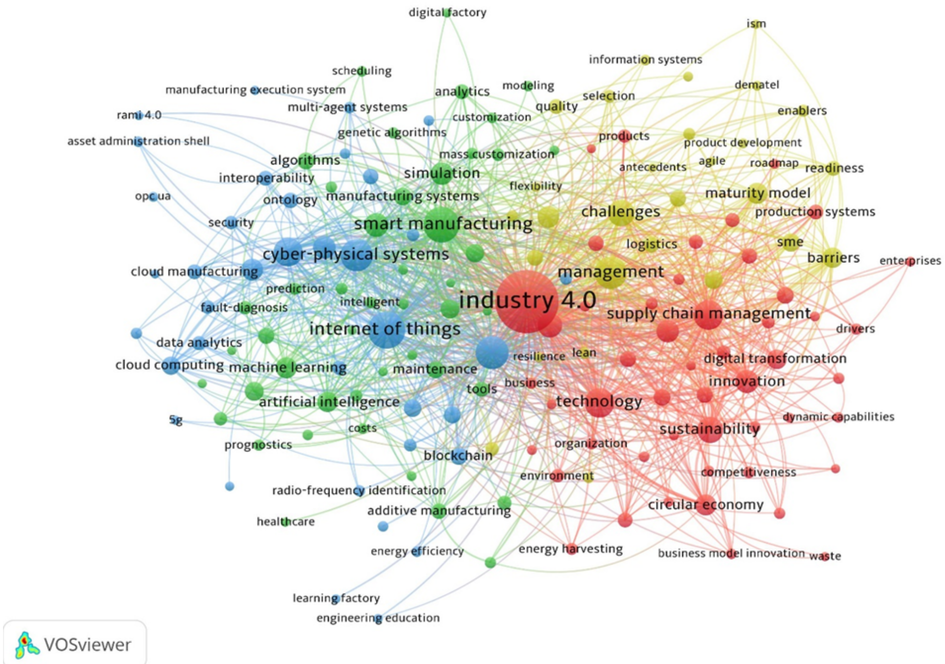

Figure 9. Network visualization of keyword co-occurrence analysis

Quality management of processes, optimization of resources, strategic use of knowledge and information, and decision-making based on data are key factors in achieving operational efficiency and desired business outcomes. All of the above research directions, together with sustainable development, environmental guidelines, and a focus on competitiveness, form an integrated framework for business process transformation and long-term industry success.Cluster 2 (green) includes 46 terms that are thematically related. Smart manufacturing is based on cutting-edge technologies that enable effective real-time engineering decisions by integrating various ICT technologies with existing production technologies [20]. The research trends based on the keywords in this cluster focus on the further development of smart manufacturing processes and technologies. The focus is on optimization, simulation, and machine learning technologies to improve various aspects of manufacturing processes. Predictive maintenance is highlighted as a key area to improve equipment reliability and reduce downtime [90]. Automation and robotics play an important role in optimizing production and achieving higher efficiency. The integration of technologies enables data-driven decision-making and improved production performance.

Table 4. Co-occurrence analysis results - the 30% most common terms from each cluster

Cluster 1	f	Cluster 2	f	Cluster 3	f	Cluster 4	f
industry 4.0	1257	smart manufacturing	311	internet of things	338	management	242
technology	191	optimization	110	big data	248	challenges	145
supply chain management	186	simulation	95	cyber-physical systems	231	integration	86
sustainability	140	machine learning	80	digital twins	174	maturity model	81
manufacturing	120	artificial intelligence	77	smart factory	94	barriers	76
innovation	105	predictive maintenance	66	industrial internet of things	89	sme	59
digitalization	94	industry	62	cloud computing	58	technology adoption	57
circular economy	82	automation	56	services	53	decision making	45
digital transformation	67	manufacturing systems	51	blockchain	48		
lean production	48	maintenance	49	augmented reality	46		
opportunities	46	algorithms	48	intelligent manufacturing systems	40		
knowledge-based systems	44	neural networks	44				
companies	41	additive manufacturing	37				
operations management	40	tools	34				
methodology	38						

f - frequency

The integration of smart manufacturing can play a key role in promoting sustainable development [16]. Mass customization of products and the capabilities of such customization is gaining attention, enabling manufacturers to meet individual customer needs while maintaining profitability. Mass customization and mass personalization enable a wide range of products, ranging from large quantities to one-of-a-kind (unique) products [38]. Quality control, defect detection and diagnosis are important aspects to ensure product reliability and safety [91-93].

Overall, the research trends in this cluster cover a wide range of topics, highlighting the multidisciplinary nature of smart manufacturing and its potential to revolutionize the industry [94]. The focus is on improving productivity, quality, and sustainability by integrating advanced technologies and innovative approaches.

Cluster 3 (blue) includes 37 keywords that can be used to explore research directions. Exploring the basic technologies of Industry 4.0 provides insights into the key concepts and tools that are shaping advanced manufacturing in today's digital age. Table 2 shows that the basic technologies of Industry 4.0 most frequently mentioned in research are the Internet of Things, Big Data, cyber-physical systems, and digital twins. The Internet of Things (IoT) is a network of physical devices and sensors connected via the Internet to exchange and manage data. The IoT enables the collection of large amounts of data in real-time, which forms the basis for making informed decisions and optimizing production processes [95]. Big Data technology refers to large and complex data sets that are generated during production and require advanced analytics techniques to gain useful insights [96]. Cyber-Physical Systems (CPS) represent the integration of computer and physical components that work together to support and optimize production processes. CPS are the fundamental technological component in the realization of Industry 4.0 [97]. These systems enable monitoring and control of production through sensors, actuators, and control systems with connections to computer systems for analysis and decision-making [98]. Digital twins are virtual replicas of physical objects, processes, or systems that enable real-time simulation, modelling, and analysis. In modern engineering and manufacturing practice, digital twins are mainly used to create accurate virtual representations of objects and simulate operations [99]. These digital models enable a deeper understanding of real objects and processes and support optimization, prediction of failures, and experimentation with new solutions before they are deployed in real production. The concept of a smart factory involves the use of advanced technologies such as IoT, CPS, digital twins, and data analytics to achieve highly automated and flexible production [100]. A smart factory uses digital technologies with the goal of optimizing production processes, increasing efficiency, reducing costs, and increasing competitiveness. However, implementation is extremely complex, and most companies do not have sufficient knowledge of the challenges or the necessary resources for implementation [75]. The Industrial Internet of Things (IIoT) is the application of the IoT concept in an industrial environment. The IIoT enables connectivity and communication between various industrial devices, sensors, and real-time data acquisition systems, opening new opportunities to optimize production processes and improve performance [101].

Cloud computing provides computing resources over the Internet and enables on-demand access to data, applications, and resources 102]. Cloud computing provides the ability to store, process, and analyze large amounts of data and facilitates collaboration, information sharing, and access to advanced data analysis tools. Intelligent manufacturing systems represent the integration of advanced technologies such as AI, machine learning, and automation into production processes. The development and implementation of intelligent manufacturing systems is a complex task that requires the integration of multiple disciplines [103]. In addition, there are other technologies such as blockchain, augmented reality, data analytics, and networks that play an important role in supporting Industry 4.0. Together, these technologies create integrated, connected and intelligent systems that transform traditional manufacturing into a modern digital environment. Consequently, with the increasing adoption of Industry 4.0 technologies, cybersecurity is playing an increasingly important role in securing and protecting systems [104].

Cluster 4 (yellow) is the smallest cluster, highlighted in yellow, and includes 28 terms. The underlying theme that emerges from the key terms is the effective management of technology adoption and integration in organizations, taking into account challenges, barriers, decision-making processes, and information management. The adoption of Industry 4.0 technologies faces both internal and external obstacles that can hinder successful implementation [105]. Internally, companies may encounter challenges such as employee resistance, lack of executive support, limited knowledge about Industry 4.0, and financial constraints [106]. Externally, regulatory compliance issues, data security concerns, low standardization, and the need for significant investment present additional hurdles. Overcoming these internal and external hurdles is critical for companies to effectively transition to Industry 4.0 and reap its benefits. Understanding and overcoming these barriers is key to overcoming difficulties and ensuring an effective transition to Industry 4.0.

Integration plays a key role in this topic, as the concept of Industry 4.0 is based on the integration of information and communication technologies and industrial technology, and is mainly based on building a cyber-physical system (CPS) to realize a digital and smart factory [107].

It requires careful planning, coordination and alignment of the various systems, processes and stakeholders. Effective integration of technologies enables organizations to realize their full potential, improve operational efficiency, foster collaboration, and drive innovation.

An important aspect of this topic is the maturity model, which provides a framework for assessing a company’s readiness and ability to implement Industry 4.0 technologies [108]. Maturity models help companies assess their current technology status, identify areas for improvement, and set guidelines for progress. They provide a structured approach to measuring progress and setting goals for achieving higher levels of technology maturity [109].

Within this theme, small and medium-sized enterprises (SMEs) are highlighted in terms of their specific challenges and opportunities in implementing and integrating technology [110]. SMEs often face resource constraints, lack of expertise, and organizational complexity that make technology implementation difficult, and often limit themselves to implementing cloud computing and Internet of Things technologies [74]. However, SMEs can also benefit from innovative solutions tailored to their specific needs.In summary, the underlying theme that emerges from the key concepts relates to the effective management of technology adoption and integration in enterprises, taking into account challenges, barriers, decision-making processes, and information management. This theme highlights the need to address challenges, integrate technologies effectively, assess organizational maturity, overcome barriers, help SMEs make informed decisions, and manage information effectively to achieve successful technology adoption and integration.

3.2.3. Evolution of the research focus

To answer RQ6 and to better understand the research structure and the current temporal dynamics within the research field under consideration, an overlay visualization with the software VOSviewer was used to visualize the progress in the implementation of Industry 4.0 technologies in manufacturing.Figure 10 shows when the frequency of co-occurrence of terms was highest, terms in yellow are more recent, earlier terms are shown from purple to green. From this visualization of the evolution of the theme over time, it can be seen that cluster 4 is an emerging thematic unit, i.e., more than 50% of the keywords in cluster 4 are younger than the other keywords in that cluster, and the highest frequency of occurrence was in 2021.

From the visual representation, it can be seen that the terms Cyber-Physical Systems, Smart Factory, Cloud Computing, Cloud Manufacturing, Simulation, Internet of Things, Industry 4.0, Big Data, Data Analytics, Sensor Networks peaked in the previous period, while newer terms that appear more frequently are Artificial Intelligence, Deep Learning, Blockchain, 5g, Edge Computing, Industry 5.0, human-robot collaboration, supply chain management, technology, drivers, sustainability, circular economy, business model innovation, lean management, technology adoption, asset administration shell, and keywords from cluster 4 (emerging): barriers, readiness, critical success factors, enablers, lean, dematel, flexibility, resilience, ism. A slight shift in researchers' interest from exploring the enabling technologies of Industry 4.0 to implementing the enabling technologies of Industry 4.0 and developing strategies, guidelines, and models for implementation can be seen. The yellow terms also indicate possible future research trends.

Figure 11 shows the density visualization of the co-occurrence analysis, which can be used to analyze the occurrence of potential research and which research areas have reached a certain level of maturity.

The keyword Industry 4.0 is located in a high-density area, which means that the connections of this word with other keywords are extremely strong.

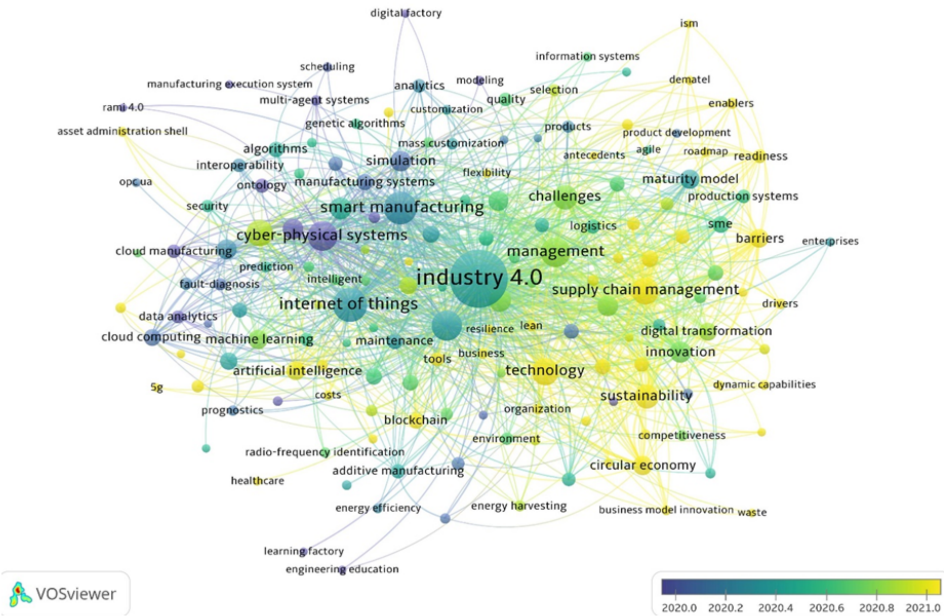

Figure10.Overlay visualization – evolution of research focus

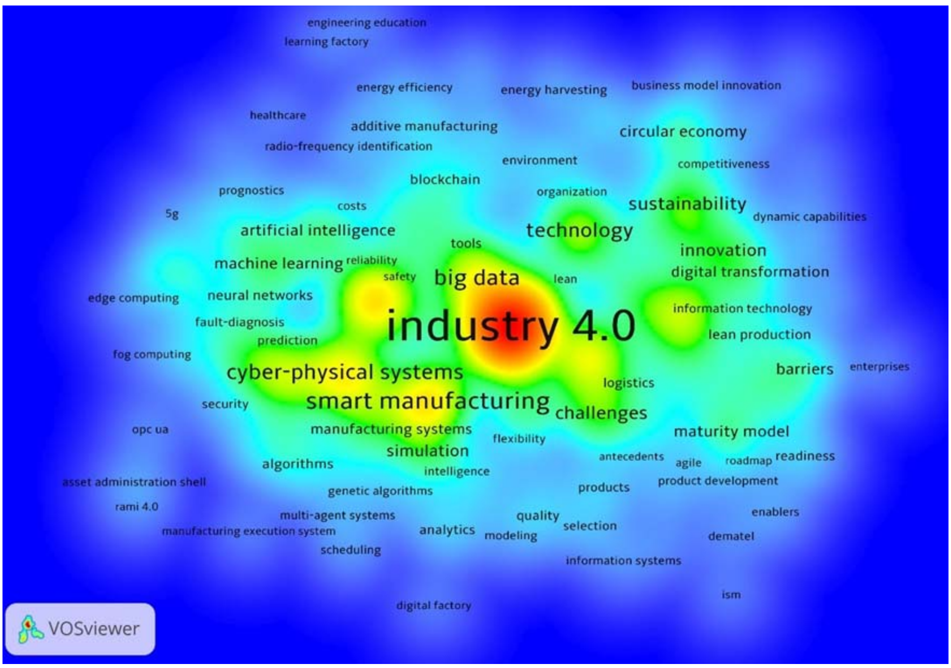

Figure 11. Keyword co-occurrence analysis - density visualization

In the yellow area with lower density are the keywords Internet of Things, smart manufacturing, Big Data and cyber-physical systems.
The keyword Industry 4.0 is located in a high-density area, which means that the connections of this word with other keywords are extremely strong. In the yellow area with lower density are the keywords Internet of Things, smart manufacturing, Big Data and cyber-physical systems. The keywords Industry 4.0 and Big Data are strongly connected according to their position in the graph. From the density visualization, it can be seen that there is only one red area, while many keywords are found in the green and blue areas. This indicates that research into the implementation of Industry 4.0 technologies in manufacturing is still in its infancy and is not mature. Consequently, there is still considerable potential for further exploration and investigation in this area.

3.2.4 Social network structure

The progress of science is the result of the collaboration of numerous scientists, both virtual and physical, who share their discoveries and build on each other's work [111]. In this study, the co-authorship analysis in VOSviewer was used to reveal the social network structure at the macro level, especially at the country level, as answer to RQ7. The analysis of country co-authorship can reveal the degree of communication between countries and the influence of countries in a particular research area. Theanalysis focused on countries with at least 10 publications and 100 citations per country. This narrowed the sample to 47 countries that met this criterion, out of a total of 97 countries considered. The method of fractal counting (the concept of fractional counting aims to mitigate the impact of documents with a large number of authors) and documents as weights were used.
The results of the co-authorship analysis are shown in Table 5 and Figures 12 and 13.

Table 5.Macro co-authorship analysis – an international collaboration

Country	Documents	Citations	Total link strength
Peoples R China	261	7032	116
USA	188	4848	90
Germany	209	4028	89
United Kingdom	153	4199	89
Italy	226	4429	75
India	186	4529	74
Brazil	123	4776	62
France	107	4897	60
Spain	104	1385	54

The table shows the countries with the highest total linkage strength, which means that they achieve the strongest cooperation with other countries (only countries with a total linkage strength of more than 50.00 are shown in the table), namely China, the United States, Germany, the United Kingdom, Italy, India, Brazil, France, and Spain.

Figure 12 shows the structure of the social network, i.e., the structure of international cooperation between countries, in research on the implementation of Industry 4.0 in the manufacturing industry. In Figure 12, it can be seen that the countries are distributed in 5 clusters and that the largest individual linkage strength, i.e., the largest cooperation in terms of co-authorship, is achieved by India and the United Kingdom (14.58) and China and the United Kingdom (13.67), followed by China and the United States with a linkage strength of 13.33, although they are not in the same cluster thematically. Different colours on the map indicate the diversity of research directions, while large nodes represent influential countries. The size of the node represents the productivity of the country (already shown in Figure 3 based on the number of publications). The links between nodes show the collaborative relationships between countries, and the distance between nodes and the thickness of links reflect the degree of collaboration. The thickness of the lines connecting the countries in the network visualization indicates the strength of the link between the countries, i.e., the number of joint publications. The thicker the line, the stronger the cooperation between these countries.

China achieves the greatest international cooperation, has the most publications, the most citations, and the greatest overall strength of connections, although it cooperates with a smaller number of countries than some other countries, such as the United States, Germany, and the United Kingdom.

Figure 13 shows the density visualization of the social network structure, highlighting the countries with the strongest cooperation with other countries (indicated by intense red colour). This visualization is based on the total strength of linkages.

In the area of implementing Industry 4.0 in manufacturing, there was the greatest international collaboration in research, led primarily by China. The following countries, in descending order, also showed significant collaboration: the United States, Germany, the United Kingdom, India, Brazil, and France. In contrast, countries in the yellow to blue range showed weaker collaboration in terms of joint research and publications. In particular, developed countries such as Japan, Canada, Ireland, and the Netherlands are less likely to collaborate with other countries in this area of research. This observation suggests that the field is still in its infancy and that international collaboration has been limited to date.

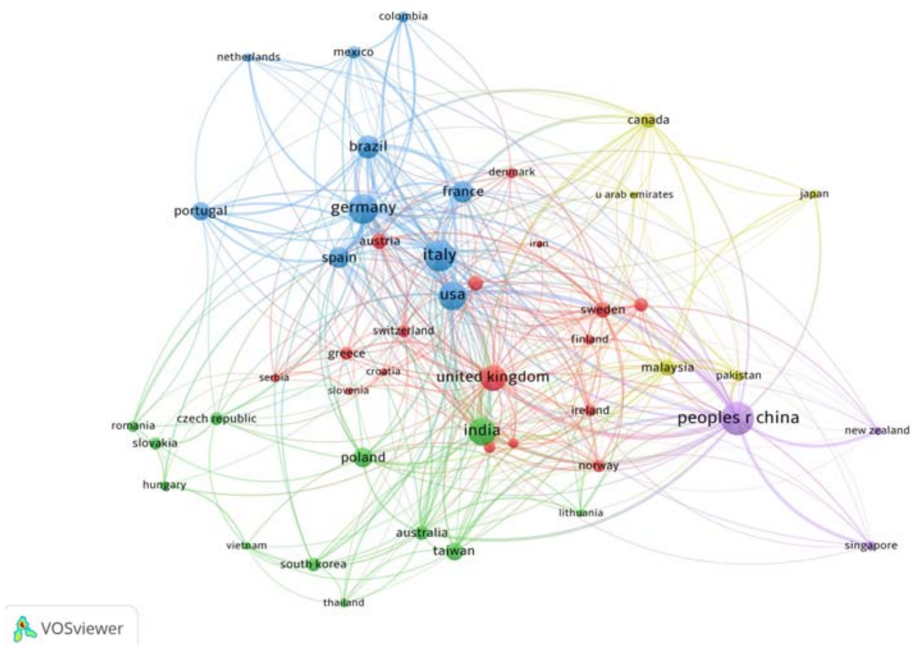

Figure 12. Social network structure

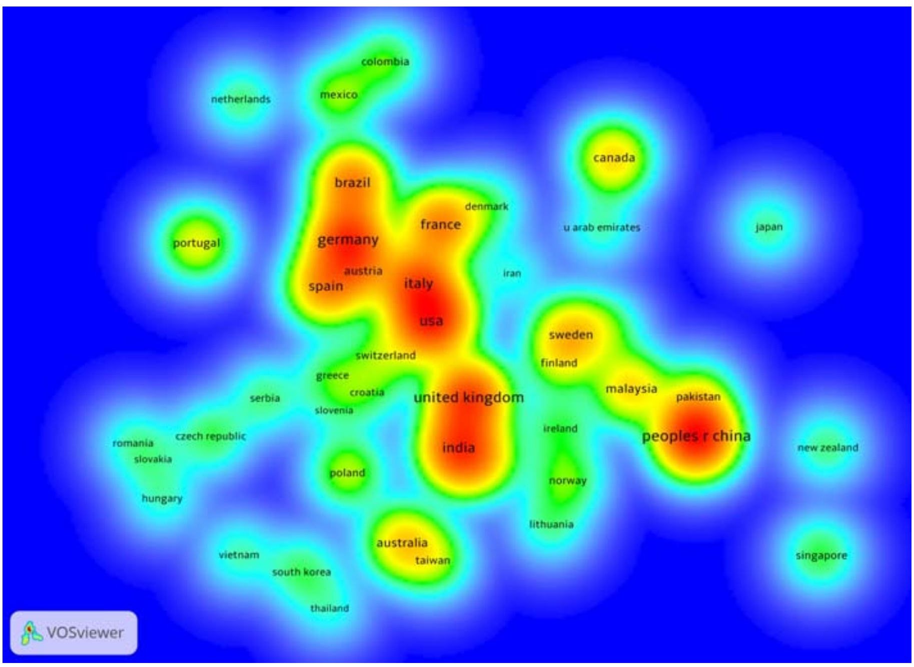

Figure 13. Social network structure – density visualization

4. Discussion

Answers to questions RQ1 through RQ7 were provided using descriptive analysis and scientific mapping.

The trend in publishing articles on the implementation of Industry 4.0 in the manufacturing industry indicates a significant increase in research output over time. A thorough analysis of the publication data shows that the number of articles published each year is increasing, indicating a growing interest and recognition of the importance of Industry 4.0 in the manufacturing industry. This trend underscores the increasing importance and impact of Industry 4.0 technologies in improving manufacturing processes and overall industrial efficiency. In identifying the countries contributing the most to research on the implementation of Industry 4.0 in manufacturing, several countries emerged as leading players. China stands out as a major player with a high number of publications and numerous citations. Following closely behind are the United States, Germany, the United Kingdom, India, Brazil and France. These countries have extensive research activities that demonstrate their commitment to researching and promoting the implementation of Industry 4.0 technologies in manufacturing. Some countries have strategies for Industry 4.0 adoption, but these are general guidelines; research on implementation models is less represented in the literature. Policy-level strategies have been adopted in developed countries that have stronger economies and greater investment opportunities in Industry 4.0. These countries are also more productive in scientific research, so the leading countries are China, Italy, Germany, the United States, India, and the United Kingdom. Developing countries face far greater challenges in implementing Industry 4.0 than developed countries with strong economies, primarily due to problems in investing in Industry 4.0 and other issues faced by both developed and developing countries.

In terms of the scientific disciplines to which the publications from the research sample belong, there is a clear concentration of publications from engineering and computer science, with production engineering and industrial engineering being prominent research areas within these disciplines. This is to be expected, as these disciplines are closely related to manufacturing. This reflects the importance of integrating Industry 4.0 technologies into manufacturing and optimizing industrial processes to improve efficiency and productivity.

As for the most cited authors, publications, and sources in the field of Industry 4.0 implementation in the manufacturing industry, there are some notable contributions, as mentioned earlier. These highly cited authors, publications, and sources identified as a result of the analysis highlight their influence and contribution to the research landscape in the area of Industry 4.0 implementation in manufacturing.

The intellectual research base for the implementation of Industry 4.0 consists of five research directions or clusters. The first cluster addresses a broader perspective of manufacturing transformation, while the second cluster examines specific technologies used in manufacturing to achieve optimization and adaptability and includes contributions published mainly in the formative stages of research on the implementation of Industry 4.0, focusing on cyber-physical systems, the Internet of Things, Big Data, and cloud computing. The third cluster focuses on the technical aspects of implementing Industry 4.0 and developing systems and strategies for successful implementation. This cluster focuses on technical details and challenges related to the implementation of Industry 4.0 principles. The fourth cluster focuses on the application of digital twins to improve production processes, while the fifth cluster explores the convergence between Industry 4.0 and lean manufacturing principles.

Despite their different focuses, all of these clusters contribute to the understanding and practical application of Industry 4.0 in the manufacturing industry.

Based on the bibliometric analysis, four main directions for future research can be derived. The future research directions emphasize ongoing exploration of advanced technologies, sustainability integration, lean manufacturing processes, and optimization techniques for production efficiency and environmental sustainability.

The conceptual structure provides valuable insights into the multidimensional aspects of digital transformation and Industry 4.0 in manufacturing. The findings highlight the importance of technology adoption, sustainability, integration of advanced technologies, effective management practices, and removal of barriers to the successful implementation of Industry 4.0 in the manufacturing industry.

The research used the VOSviewer software to visualize the temporal dynamics and research structure in the field of implementing Industry 4.0 technologies in manufacturing. The overlay visualization showed the emergence of cluster 4 as a thematic entity characterized by newer keywords compared to other clusters, and its maximum frequency of occurrence was observed in 2021. Meanwhile, earlier terms such as Cyber-Physical Systems, Smart Factory, Cloud Computing, and Internet of Things had peaked in earlier time periods.The analysis also showed a shift in research interest from exploring the enabling technologies of Industry 4.0 to their practical implementation. Newer concepts such as artificial intelligence, deep learning, blockchain, 5G, edge computing, asset administration shell, ism, and dematelgained prominence, as did concepts such as Industry 5.0, human-robot collaboration, and supply chain management. This shift shows that the research community is increasingly focused on developing strategies, policies and models for effective implementation. In addition, the presence of yellow terms in the visualization indicates potential future research trends in this area. Standardization and interoperability are essential to the successful implementation of Industry 4.0, and a key enabler for the manufacturing sector is the Asset Administration Shell (AAS) [112]. AAS is an integral part of the Reference Architecture Model for Industry 4.0 (RAMI 4.0) [113] and provides a standardized electronic representation of industrial assets. AAS plays a critical role in realizing the vision of Industry 4.0 by ensuring compatibility and harmonization between different technologies and systems within the industrial domain. AAS (Asset Administration Shell) and DT (Digital Twin) are two intersecting concepts within the realm of Industry 4.0, but while there is overlap between the two, they represent distinct aspects of the digital transformation in industrial processes[114].The presence of AAS (Asset Administration Shell) is evident in both the bibliometric analysis of Cluster 1 - Smart Manufacturing and Industry 4.0 Technologies Integration and the conceptual structure of Cluster 3 - Industry 4.0 Technologies and Integration. However, the science mapping analyses highlight the relatively limited research on the asset management shell model, as shown in the density visualization (as a blue area representing a poorly researched concept). Given the critical importance of interoperability to the successful implementation of Industry 4.0, it is important to increase research efforts in this area. In addition, other potential topics such as ISM (Interpretive Structural Modelling) and DEMATEL (Decision-Making Trial and Evaluation Laboratory), as well as emerging technologies such as artificial intelligence, deep learning, blockchain, 5G, and edge computing, have gained attention in recent research studies and offer further opportunities to explore the implementation of Industry 4.0 technologies in manufacturing.The density visualization of the keyword co-occurrence analysis showed that Industry 4.0 is strongly associated with other keywords, especially Big Data, indicating a strong interrelationship between these concepts. Co-authorship analysis revealed the social network structure of international collaboration in implementing Industry 4.0 in manufacturing. China led in terms of collaboration, followed by the United States, Germany, the United Kingdom, India, Brazil, and France. Developed countries showed limited collaboration, indicating the early stage of international cooperation. China achieved the greatest collaboration despite working with fewer countries. The findings emphasize the need for increased global cooperation in this research field.

5. Conclusion

Given the extensive scientific activity and research that has been conducted in recent years on the topic of Industry 4.0, it is evident that the effective implementation of its principles and technologies in the real manufacturing world remains a major challenge. This discrepancy arises from the gap between the technological capabilities and the practical implementation of their benefits in the manufacturing industry. The manufacturing sector is currently in the process of adopting Industry 4.0, facing obstacles such as outdated infrastructures, security concerns, the need for organizational culture change, and a shortage of skilled workers. Nonetheless, there is growing recognition of the growing momentum in implementing Industry 4.0 and its potential to profoundly impact the manufacturing in the future. This growing awareness has motivated us to conduct an extensive literature review on this topic to examine existing research and gain valuable insights into the implementation of Industry 4.0. Although there are literature analyses on this topic and the application of bibliometric methods in the related literature, to the knowledge of the authors of this study, there is no comprehensive bibliometric approach that addresses the state of research on the implementation of Industry 4.0 and in which comprehensive analyses are applied as in this study.

The bibliometric analysis conducted in this study provided a comprehensive examination of specific patterns, trends, and implications within the research community related to the implementation of Industry 4.0 technology in the manufacturing industry. The study underscores the transformative potential of Industry 4.0 in manufacturing and emphasizes the importance of continuous research, collaboration and strategic planning to fully realize the benefits of these technologies. Industry 4.0 offers manufacturing companies the opportunity to increase productivity, efficiency and competitiveness in a dynamic global environment. By overcoming challenges and leveraging advanced technologies, companies can revolutionize operations and drive innovation, paving the way for long-term success. The findings highlight emerging technologies such as artificial intelligence, deep learning, blockchain, 5G, asset administration shell, highlighting their relevance and potential impact on the implementation of Industry 4.0 in manufacturing. The findings serve as a valuable guide for researchers, policy makers and stakeholders, enabling informed decisions on technology adoption, process optimization and overall digital transformation.

To fully realize the potential of Industry 4.0, it is also important to conduct further research focusing on the integration and interoperability of different technologies and systems in the context of manufacturing.

Further research is needed on how these technologies can work together seamlessly to enable efficient data exchange and collaboration between the various components of the manufacturing ecosystem. By addressing these research gaps, companies can overcome barriers, ensure successful implementation, and realize the full potential of Industry 4.0 in manufacturing. This will lead to advances in productivity, efficiency and competitiveness and shape the future of the manufacturing industry.

The limitation of this study is that it focuses specifically on the implementation of Industry 4.0 technologies in the manufacturing industry only. It does not cover other industries or sectors where Industry 4.0 may have other impacts and challenges. In addition, the analysis is based on data from the Web of Science

Core Collection, which may not include all relevant publications on the topic. The results and conclusions of the study are based on the available data and may be affected by any biases or limitations within the dataset. Despite the limitations, this study provides valuable insights that contribute to a better understanding of the relevant aspects of Industry 4.0 implementation.

6. References

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Edge AI: Reshaping the Future of Edge Computing with Artificial Intelligence

Lejla Banjanović-Mehmedović[1*], Anel Husaković[2]

Abstract: *This paper highlights the growing importance of edge computing and the need for AI techniques to enable intelligent processing at the edge. Edge computing has emerged as a paradigm shift that brings data processing and storage closer to the source, minimizing the need for transmitting large volumes of data to remote locations. The integration of AI capabilities at the edge enables intelligent and real-time decision-making on resource-constrained devices. This paper discusses the significance of Edge AI across various domains, including automotive applications, smart homes, industrial IoT, and healthcare. By leveraging AI algorithms on edge devices, efficient implementation and deployment become possible, leading to improved latency, privacy, and security.The various AI techniques used in edge computing are presented, including machine learning, deep learning, reinforcement learning and transfer learning.*

As AI continues to play a pivotal role in driving edge computing, the integration of hardware accelerators and software platforms is gaining utmost significance to efficiently run inference models. A variety of popular options have emerged to accelerate AI at the edge, and notable among them are NVIDIA Jetson, Intel Movidius Myriad X, and Google Coral Edge TPU. The importance of specialized System-on-a-Chip (SoC) solutions for Edge AI, capable of supporting high-performance video, voice, and vision processing alongside integrated AI accelerators is presented as well.

By examining the transformative potential of Edge AI, this paper aims to inspire researchers, practitioners, and industry professionals to explore the vast possibilities of integrating AI at the edge. With Edge AI reshaping the future of edge computing, intelligent decision-making becomes seamlessly integrated into our daily lives, driving advancements across various sectors.

Keywords: *artificial intelligence, Edge AI, Edge computing, Edge Intelligence, embedded systems, FPGA, Industry 4.0, System-on-Chip (SoC)*

1. Introduction

Throughout the years, technology has undergone a series of transformations in data storage, transitioning from centralized mainframes to personal computing, and eventually to cloud computing. However, the current paradigm shift involves a departure from relying solely on data centers for hosting and

[*1]University of Tuzla, Faculty of Electrical Engineering, Tuzla, Bosnia and Herzegovina
[2]EaconZenica, Bosnia and Herzegovina
E-mail: lejla.banjanovic-mehmedovic@fet.ba

processing information. The concept of edge computing brings computation and data storage closer to the source, thereby minimizing the necessity of transmitting large volumes of data to remote locations. Edge computing refers to the paradigm of bringing computational power and data storage closer to the source of data generation, enabling faster processing and real-time decision-making. By processing data locally, edge computing reduces the time it takes for data to travel back and forth between the edge and the cloud, enabling faster response times and enhancing the reliability of applications. This approach reduces latency, conserves network bandwidth, enhances data privacy, and improves the overall efficiency of the system. It allows data to be filtered, aggregated, and analyzed locally, transmitting only the necessary insights or actionable information to the cloud[1-5].Edge computing concept is presented in Figure 1.

Edge computing allows for selective data processing at various levels. Subsequently, it categorizes the data into two main types [6]:

- ‘’Hot’’ Data: Hot data refers to crucial signals that need to be transmitted to the production line’s supervision system for immediate action.
- ‘’Cold’’ Data: Cold data typically consists of historical data sets containing parameters such as pressure and temperature. This data is valuable for subsequent predictive analysis.

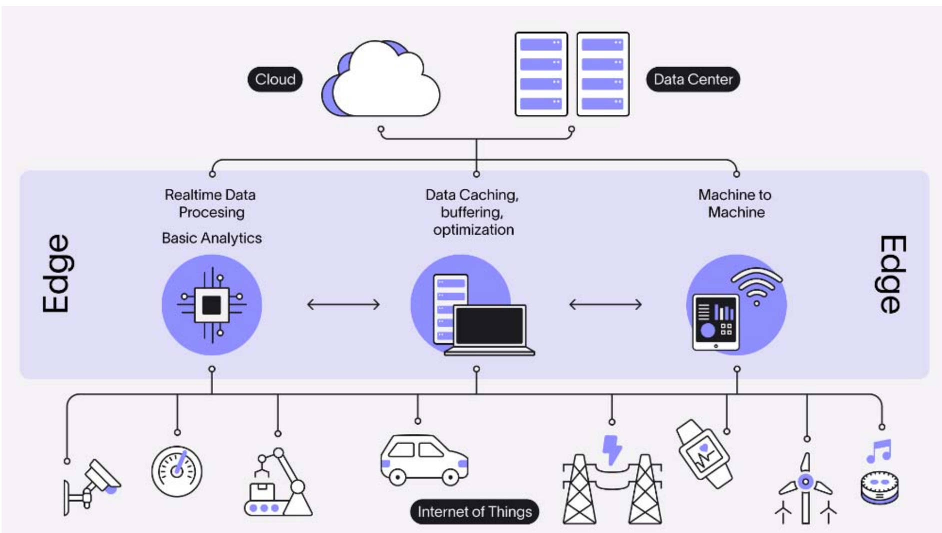


Figure 1. Edge Computing concept [7]

The edge computing applications cover a wide range of industries and use cases, fromsmart cities, autonomous cars, manufacturing, healthcare systems, toward Augmented Reality (AR) and Virtual Reality (VR), Figure 2.

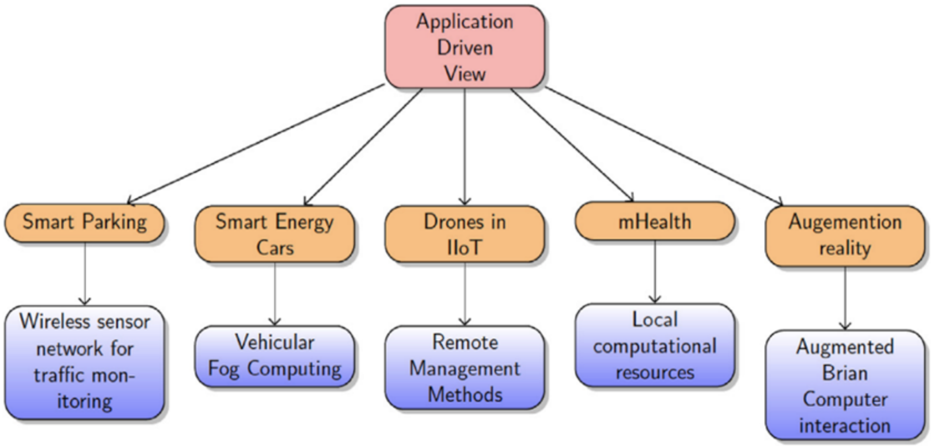


Figure2. Taxonomy of Edge computing applications [8]

In certain cases, there can be multiple layers, leading to the creation of the term ''fog computing'' as an analogy to cloud computing.

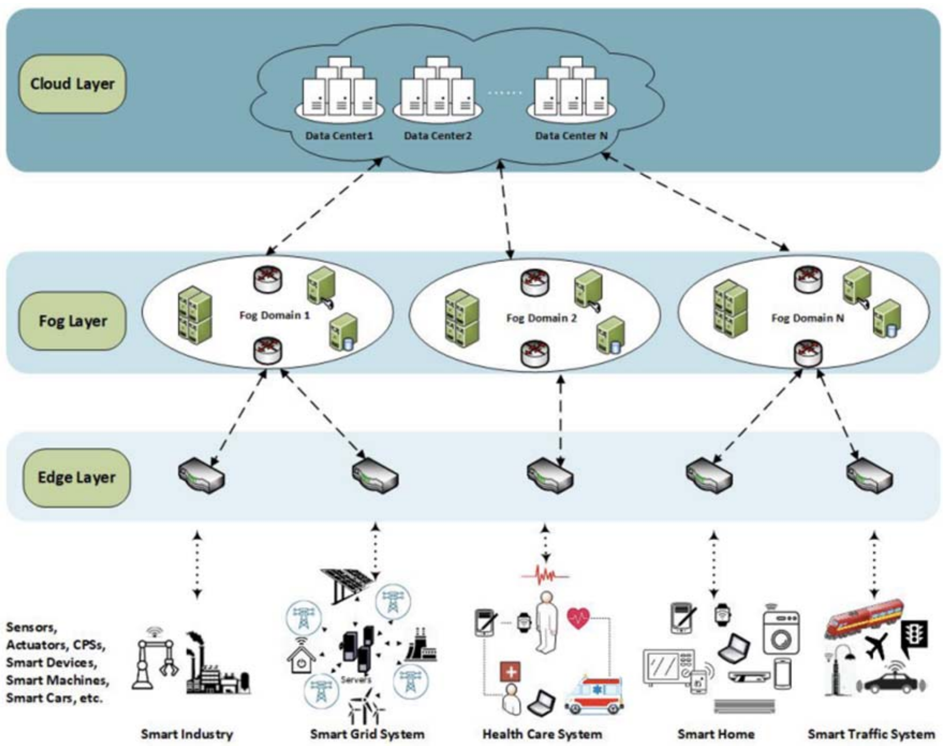


Figure 3. FogComputing concept [9]

Nowadays, the term ‘’fog computing’’ is gaining popularity within the industrial community. While ‘’cloud’’ signifies the highest and most widely distributed levels, ‘’fog’’ represents the intermediate levels situated between the edge and the cloud, as shown in Figure 3. It addresses some of the data congestion issues.
At the same time, smarter devices are driving the data migration from cloud to edge. Edge AI refers to the deployment of artificial intelligence (AI) algorithms and models directly on edge devices, such as embedded systems, smartphones, Internet of Things (IoT) devices, and other local computing devices, rather than relying on cloud-based computing resources. In the Edge AI scenario, advanced AI models based on machinelearning (ML) algorithms will be optimized to run on the edge, as shown in Figure 4. It enables real-time complex data processing and analysis on the edge devices, reducing the need for constant data transmission to the cloud and enabling faster response times. Edge AI has several advantages over cloud-based AI solutions. Firstly, it reduces latency by processing data locally, which is crucial for applications that require real-time decision-making or low-latency responses. Secondly, it reduces the dependency on cloud connectivity, making it suitable for scenarios where there are limited or unreliable network connections.

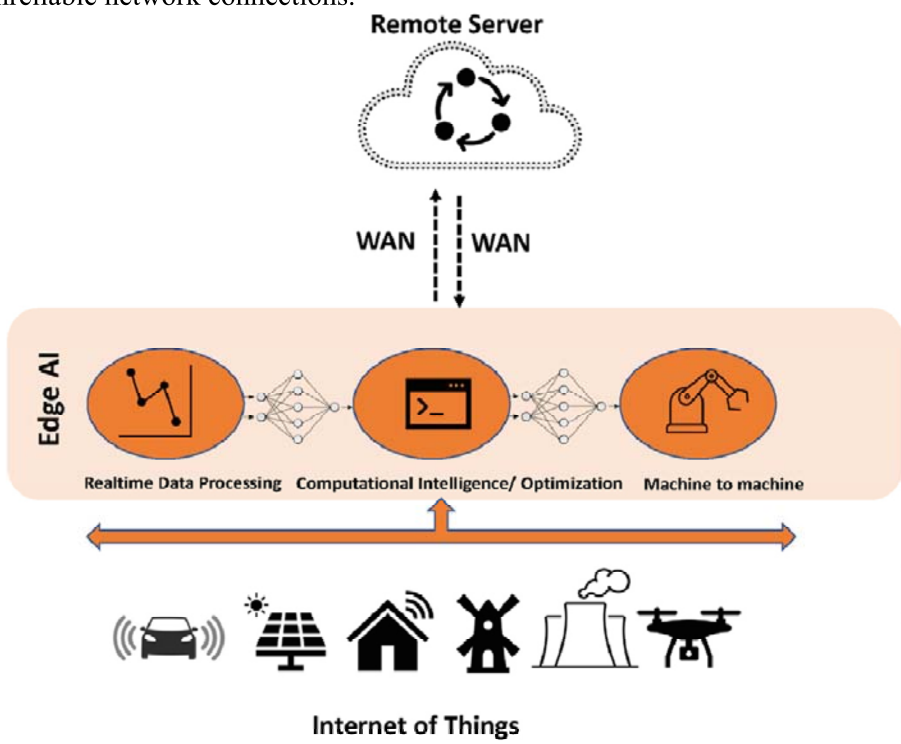


Figure 4.Edge AI concept[8]

Thirdly, it addresses privacy and security concerns by keeping sensitive data on local devices, minimizing the risk of data breaches, and ensuring data privacy.
Edge AI is increasingly being used in various domains, including smart homes, autonomous vehicles, healthcare, industrial automation, robotics, and surveillance systems. For example, in smart homes, edge AI can enable voice recognition and natural language processing directly on smart speakers or home automation hubs. In autonomous vehicles, edge AI enables real-time object detection and decision-making on-board the vehicle, reducing the dependence on cloud connectivity [10-11].
Edge Computing and Edge AI are related concepts but have distinct focuses at scope and objectives, computing infrastructure and functionality[1-2, 12-13]:

- *Scope and Objective.*Edge computing is a distributed computing paradigm that brings computing resources closer to the data source or the edge of the network. Its primary objective is to reduce latency, optimize network bandwidth, and enable real-time data processing and analysis at the network edge.Edge AI specifically refers to the deployment of artificial intelligence algorithms and models directly on edge devices. The objective of Edge AI is to enable AI capabilities at the edge, allowing local data processing, real-time decision-making, and intelligent behaviour without relying heavily on cloud resources.
- *Computing Infrastructure.*Edge computing involves the deployment of computing resources, such as edge servers, gateways, or routers, at the network edge. These devices provide computational power and storage capacity to process and analyze data closer to the source.Edge AI leverages the computing infrastructure of edge devices themselves, such as smartphones, IoT devices, or embedded systems. AI algorithms and models are deployed directly on these devices to enable local AI processing and decision-making.
- *Functionality.*Edge computing focuses on optimizing data flow, reducing latency, and improving the overall performance of applications by processing data closer to the edge. It facilitates tasks such as data aggregation, filtering, and forwarding to the cloud or other edge nodes.Edge AI builds upon edge computing by specifically incorporating AI capabilities at the edge. It allows for intelligent data processing, analysis, and decision-making on the edge devices themselves. Edge AI algorithms enable tasks like object recognition, predictive analytics, and real-time response directly on the edge devices.

2. Objectives and Functionalities of Edge AI

The key objectives of Edge AI are as follows:

- *Low Latency.* Edge AI aims to reduce the latency involved in data processing and decision-making by performing AI tasks directly on edge devices. This objective is important for real-time applications such as autonomous vehicles, industrial automation, and interactive systems[1].
- *Privacy and Security.* Edge AI focuses on keeping sensitive data on local devices, enhancing data privacy, and reducing the risk of data breaches. By processing data locally on edge devices, sensitive information can be kept within the local environment, reducing the risk of data breaches and unauthorized access. This objective is particularly important when dealing with sensitive data in applications like healthcare, finance, and surveillance systems [2,3].
- *Bandwidth Optimization.*Edge AI aims to optimize bandwidth consumption by minimizing the need for continuous data transmission to the cloud. By performing data processing and analysis at the edge, only relevant insights or summarized information can be transmitted, reducing the amount of data sent over the network. This optimization is crucial in scenarios with limited network connectivity or where bandwidth constraints exist[4].
- *Offline Operation.* Edge AI enables AI algorithms to operate effectively even in offline or intermittent connectivity scenarios. By deploying AI capabilities on edge devices, they can continue to function autonomously and make decisions locally without relying on constant cloud connectivity[2].
- *Energy Efficiency.* By processing data locally, Edge AI can reduce the amount of data sent over the network, leading to energy savings. Additionally, specialized edge AI hardware accelerators can further optimize energy consumption.
- *Scalability and Adaptability.*Edge AI aims to provide scalable and adaptable solutions that can cater to diverse edge devices and evolving application requirements. It focuses on developing lightweight and efficient AI algorithms that can run effectively on resource-constrained edge devices, ensuring flexibility and compatibility across different hardware platforms[14].
- *Real-time Data Analysis.* With Edge AI, data can be analyzed and filtered locally, enabling edge devices to provide real-time insights without the need for round-trip communication to the cloud.

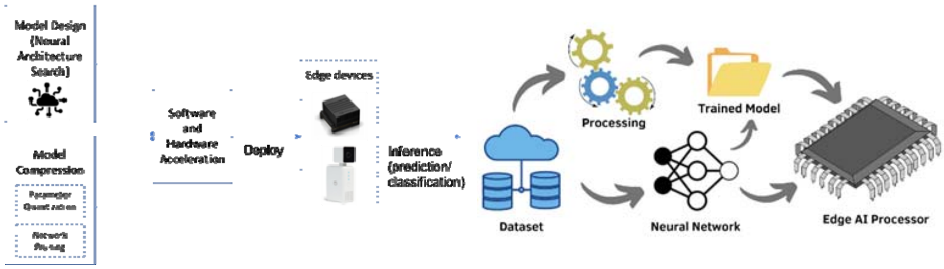
The key functionality in Edge AI enables local data processing, real-time decision-making, contextual understanding, and resource optimization, empowering edge devices to perform intelligent tasks and contribute to efficient and autonomous edge computing systems[2, 15-16]:

- *Data Processing and Analysis.* Edge AI algorithms are designed to process and analyze data generated by edge devices. This includes tasks such as data filtering, feature extraction, pattern recognition, and anomaly detection. By performing these computations locally, edge devices can extract meaningful insights from raw data and make informed decisions.
- *Real-time decision-making.* Edge AI enables edge devices to make autonomous and real-time decisions based on locally processed data. This includes tasks such as object recognition, classification, prediction, and control. By deploying AI models directly on edge devices, quick decision-making can be achieved, reducing the need for constant communication with the cloud.
- *Contextual Understanding.* Edge AI algorithms aim to understand the context in which the edge devices operate. This involves capturing and interpreting environmental cues, user interactions, and situational awareness. By understanding the context, edge devices can adapt their behaviour and responses accordingly.
- *Resource Optimization.*AI functionality in Edge AI also focuses on optimizing resource usage on edge devices. This includes techniques such as model compression, quantization, and optimization to reduce computational requirements and memory footprint. These optimizations ensure efficient execution of AI algorithms on resource-constrained edge devices.

3. The Key Technologies of Edge AI

Several key technologies collectively contribute to the efficient implementation and deployment of AI at the edge, enabling real-time and intelligent decision-making on resource-constrained devices:

- *Edge Data Management.* Efficient data management techniques, including data filtering, aggregation, and pre-processing, are employed to reduce the amount of data transmitted and processed at the edge. This helps in conserving network bandwidth and computational resources[17-18].
- *Model Optimization and Compression.*Model optimization techniques are employed to deploy AI models on edge devices with limited resources, as shown in Figure 5. These techniques include quantization, pruning, knowledge distillation, and model compression, reducing the model size and computational requirements while maintaining acceptable accuracy[19-20].



a). *b).*

Figure 5. Model Optimization and Compression: a). block-diagram,b). visual presentation [21,22]

- *Edge Device Hardware.*Edge AI accelerators are specialized hardware components designed to accelerate AI computations on edge devices, as shown in Figure 6. The advancements in hardware technologies, such as low-power processors, accelerators (e.g., GPUs, FPGAs), and dedicated AI chips (e.g., TPUs, NPUs), play a crucial role in enabling efficient execution of AI algorithms on edge devices with limited power and computational capabilities[23-24].

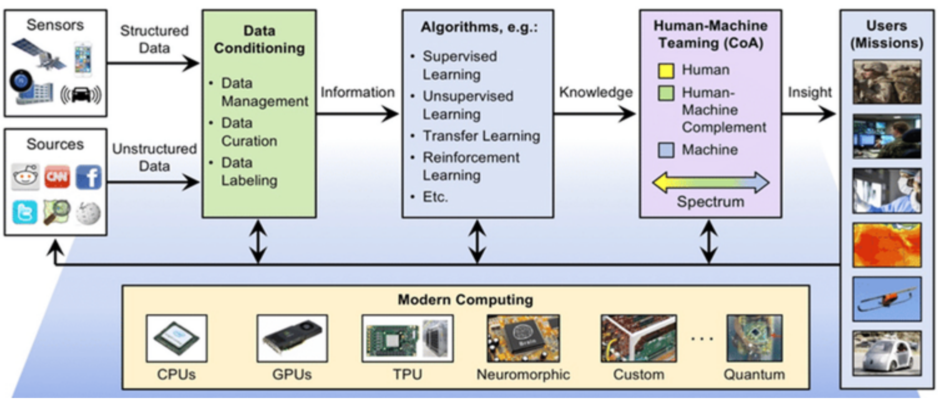


Figure 6. Edge Device hardware and AI algorithms in Edge AI [25]

- *Federated Learning.* Federated learning is a decentralized approach that allows multiple edge devices to collaboratively train a global AI model while keeping their data locally. The global model is updated with contributions from each device, minimizing data privacy concerns [26-27].

- *Edge-Cloud Collaboration.* In this paradigm, some parts of the AI processing occur on the edge device, while more resource-intensive or complex computations are offloaded to the cloud. This approach strikes a balance between local processing and cloud assistance to optimize performance and resource utilization. A real-time and robust fault detection approach through cooperation betweencloud and edge servers is presented in the paper [28].

3.1. Edge Device Hardware

FPGA (Field-Programmable Gate Array) and SoC (System-on-a-Chip) are two hardware technologies commonly used in Edge AI applications to accelerate AI computations and enable efficient deployment at the edge. FPGA is a reconfigurable hardware device that can be programmed to implement custom digital circuits and algorithms. In Edge AI, FPGAs are used to accelerate AI computations by offloading specific tasks or neural network models onto the FPGA hardware. FPGAs also offer flexibility as they can be dynamically reprogrammed or updated with new AI models or algorithms as needed[29-31].
SoC refers to a complete computing system integrated onto a single chip. It typically includes processing units (such as CPUs or GPUs), memory, I/O interfaces, and other components necessary for a functional system. SoCs provide a compact and power-efficient solution for deploying AI at the edge. They combine computational power with integrated components, enabling edge devices to perform AI tasks locally without relying on external computing resources. SoCs are commonly found in devices like smartphones, IoT devices, and edge servers, making them suitable for various Edge AI applications.
An architecture of on-device ML models is presented inFigure 7.

Figure7. Architecture of on-device ML models [32]

As AI continues to play a pivotal role in driving edge computing, the integration of hardware accelerators and software platforms is gaining utmost significance to efficiently run inference models. A variety of popular options have emerged to accelerate AI at the edge, and notable among them are NVIDIA Jetson, Intel Movidius Myriad X, and Google Coral Edge TPU. These cutting-edge solutions offer powerful capabilities to enable seamless AI processing at the edge of networks, catering to diverse applications and requirements[33].

1. *Vision Processing Unit (VPU).*Vision Processing Units (VPUs) are a critical component in efficiently handling demanding computer vision and edge computing AI tasks. They strike a balance between power efficiency and compute performance, making them ideal for such workloads. An example of a popular VPU is the Intel Neural Computing Stick 2 (NCS 2), which is built upon the Intel Movidius Myriad X VPU. The Myriad X VPU employs a clever architectural environment that minimizes data movement by running programmable computation

strategies alongside workload-specific hardware acceleration. A standout feature of the Myriad X VPU is the Neural Compute Engine, an intelligent hardware accelerator designed for deep neural network inference. It is fully programmable with the Intel Distribution of the OpenVINO Toolkit, allowing for flexible and efficient implementation of AI workloads.

With the Myriad Development Kit (MDK), developers can harness the power of the Myriad X VPU to create custom vision, imaging, and deep neural network applications using preloaded development tools, neural network frameworks, and APIs.

2. *Graphics Processing Unit (GPU).*The Graphics Processing Unit (GPU) is a specialized chip known for its rapid processing capabilities, particularly in handling computer graphics and image processing. In the context of AI at the Edge, GPUs play a crucial role in bringing accelerated performance in a power-efficient and compact form factor.One noteworthy device family enabling this accelerated AI performance at the Edge is NVIDIA Jetson. Take, for example, the NVIDIA Jetson Nano development board, which comes equipped with a 128-core GPU and Quad-core ARM CPU. Coupled with nano-optimizedKeras and TensorFlow libraries provided by the NVIDIA Jetpack SDK, it enables seamless execution of neural networks with minimal setup requirements.Not to be left behind, Intel has also entered the discrete graphics processor market with the release of the Xe GPUs. These GPUs, optimized for AI workloads and machine learning tasks, focus on achieving state-of-the-art performance with reduced power consumption.An example of architecture of NVIDIA Jetson Xavier NXA used for real-time deep lane detection system is presented in Figure 8.
3. *Tensor Processing Unit (TPU).* A Tensor Processing Unit (TPU) is a specialized AI hardware designed to efficiently execute machine learning algorithms, particularly those based on artificial neural networks (ANN). The Google Coral Edge TPU stands out as Google's purpose-built ASIC for edge AI processing.
   The Google Coral TPU, tailored for edge environments, serves as a powerful toolkit enabling local AI production. Its onboard device inference capabilities empower users to develop a wide range of on-device AI applications with several core advantages: very low power

consumption, cost-efficiency, and offline capabilities.Google Coral devices support various machine learning frameworks, including TensorFlow Lite, YOLO, and R-CNN, enabling tasks like Object Detection and Object Tracking in video streams from connected cameras. This makes them highly versatile for AI applications at the edge.

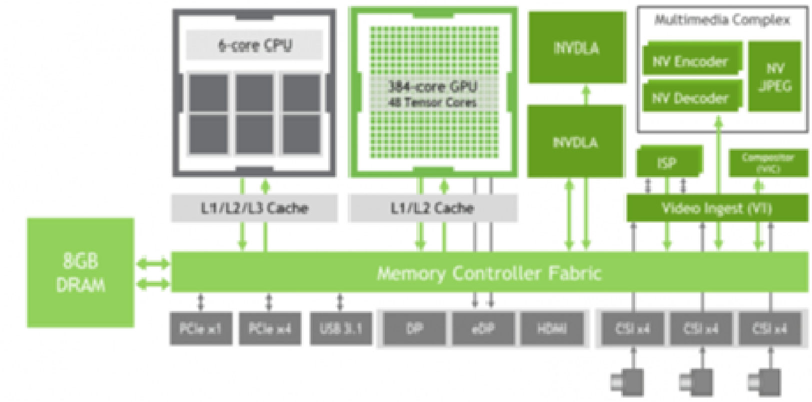


Figure 8. Architecture of NVIDIA Jetson Xavier NX[34]

Edge AI solutions have traditionally centered around camera vision, especially in automotive settings. However, in the context of smart homes, a more comprehensive approach is needed, incorporating video AI, voice AI, and vision AI for a multi-modal Human-Machine Interface (HMI). To achieve this, an ideal solution would involve a specialized System-on-a-Chip (SoC) specifically designed for smart homes, equipped to handle high-performance video, voice, and vision processing, while also featuring an integrated AI accelerator.

Such a solution would begin with an SoC platform that seamlessly integrates various types of processor engines, such as CPU, NPU, FPGA, and GPU, along with interfaces optimized for high-performance cameras and displays. This architecture enables a well-balanced combination of secure, cost-effective inferencing, and real-time, multi-mode performance.

The Synaptics Edge AI family offers a range of highly targeted SoCs, each tailored to address the specific demands of different consumer applications. Each SoC within this family comes equipped with the necessary processing cores and an appropriate level of integrated AI performance to best serve its intended application [35]. By providing a versatile and efficient edge AI solution, Synaptics aims to enhance the smart home experience and empower a seamless interaction between users and their connected devices.

One example of SoC device is the ''Versal AI Edge'' SoC that runs Linux on 1.76GHz Cortex-A72 with two cores and with two 750MHz Cortex-R5F cores, and additionally contains a flexible and FPGA-like ''adaptive core'' with up to 520K LUTs and an ''AI -ML'' core with up to 479 TOPS, as shown in Figure 9.

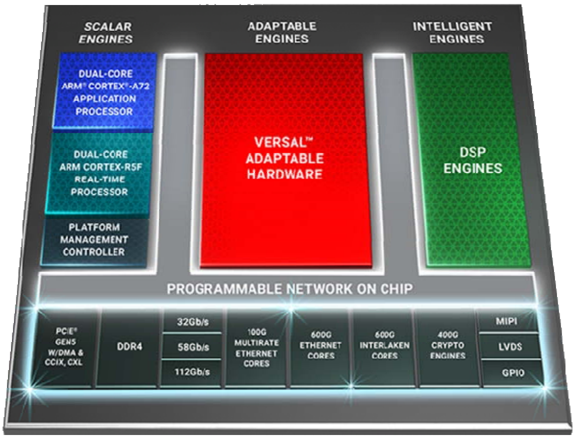


Figure 9. Architecture of Versal AI Edge[36]

Versal AI Edge SoC offers 10x higher computing power density compared to 16nm Zynq UltraScale+ and up to 4x AI performance per watt compared to Nvidia Jetson AGX Xavier module. The energy consumption of such systems starts with 6W, and for the needs of more demanding applications, they can be configured to work at up to 75 W.

4. AI techniques at Edge

Edge AI relies on a variety of artificial intelligence (AI) techniques to enable intelligent processing and decision-making at the edge devices themselves. Here are some common AI techniques used in edge AI [37-41], shown in Figure 10:

- *Machine Learning (ML).*Machine learning plays a crucial role in Edge AI applications by enabling edge devices to perform intelligent data analysis and decision-making locally. ML algorithms, including traditional techniques such as decision trees, K-Means and Fuzzy Clustering, K-Nearest Neighbours (KNN), Support Vector Machine (SVM), Multilayer feed-forward neural network[42], are employed in Edge AI to process data and extract meaningful insights. Neural networks are capable of learning complex patterns and extracting meaningful features from data.

- *Deep Learning (DL).*The most popular deep learning models in Edge AI applications are convolutional neural networks (CNNs) and recurrent neural networks (RNNs). CNN consists of multiple layers, including convolutional layers, pooling layers, and fully connected layers. The convolutional layers apply filters to the input image, detecting features such as edges, corners, and textures. The pooling layers down sample the feature maps, reducing the spatial dimensions while preserving the important features. The fully connected layers at the end of the network perform classification or regression based on the learned features [43-44]. In edge AI applications, CNNs can be deployed on edge devices to perform tasks such as object detection, image classification, face recognition, and video surveillance. RNN (Recurrent Neural Network) and LSTM (Long Short-Term Memory) are types of neural network architectures commonly used in edge AI applications for sequential data analysis, such as speech recognition, natural language processing, and time series forecasting. They are well-suited for tasks that involve processing data with temporal dependencies and have the ability to retain information from past inputs[45-46].
- *Transfer Learning.* Transfer learning involves leveraging pre-trained models on large datasets and fine-tuning them on edge devices with limited data. This technique enables edge devices to benefit from the knowledge and features learned from powerful central servers or cloud-based models.

  Transfer learning is a powerful technique in Edge AI that allows leveraging pre-trained models on large-scale datasets and adapting them to specific tasks or domains with limited labeled data. By using transfer learning, edge devices can benefit from the knowledge learned from a source domain and apply it to a target domain, leading to improved performance and faster deployment [47-48].

- *Reinforcement Learning (RL).* RL techniques can be applied to edge AI scenarios where devices learn through trial and error to optimize their decision-making processes. RL enables autonomous learning and decision-making based on rewards and penalties received from the environment. RL (Reinforcement Learning) and DRL (Deep Reinforcement Learning) are powerful techniques used in edge AI applications to enable intelligent decision-making in dynamic environments [49-50]. DRL extends RL by incorporating deep neural networks to handle complex state and action spaces, enabling more efficient and scalable learning. Edge AI, RL and DRL have several applications, such as autonomous systems, robotics, smart IoT devices, and resource management.

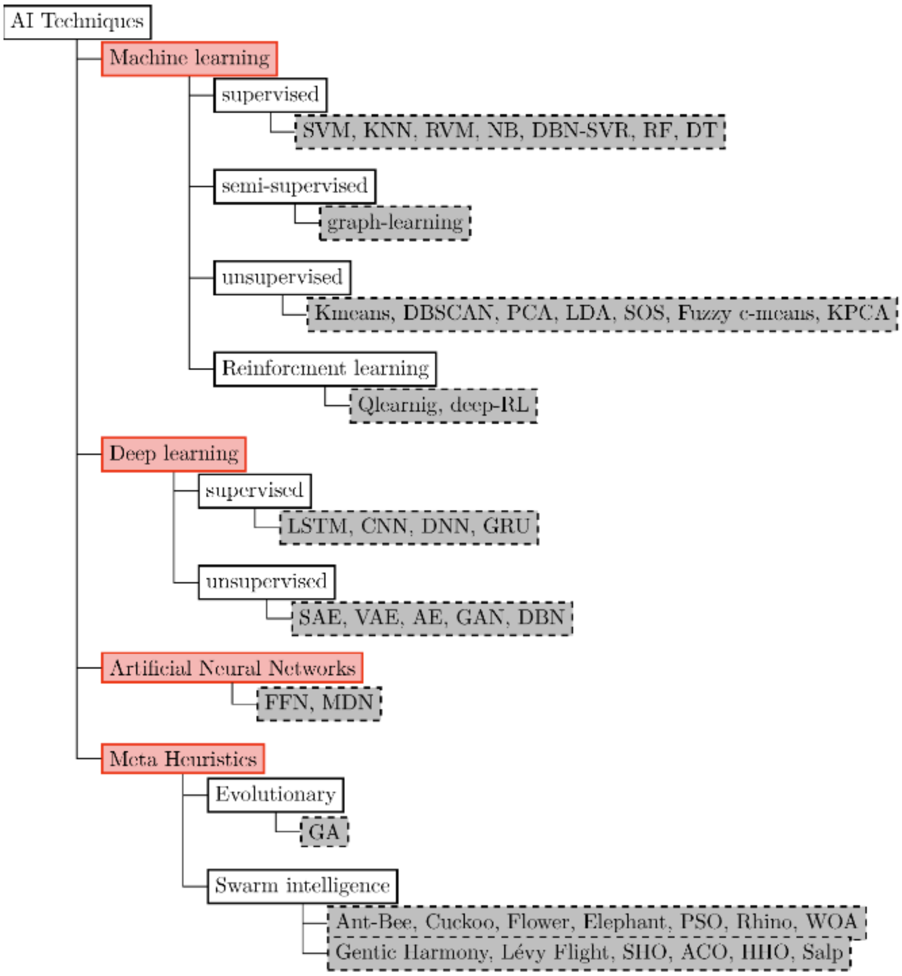


Figure 10. Categorization of AI techniques [41]

- *Meta Heuristics.*AI techniques are gaining increasing prominence in engineering as effective tools to tackle optimization problems [51]. Optimization tasks involve intelligent searches within large-dimensional spaces containing numerous decision variables, aiming to locate points that either minimize or maximize a specified objective function. Evolutionary computing, which draws inspiration from natural selection and collective behavior patterns in nature, has emerged as a popular approach for optimization. Nature-inspired optimization heuristics, such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization Algorithm (ACO), Artificial Bee Colony (ABC), and Firefly algorithms, have demonstrated the ability to optimize diverse applications, surpassing the limitations of traditional optimization techniques.Among the subfields in this domain, two particularly relevant ones are genetic algorithms (GA) and swarm intelligence, exemplified by Particle Swarm Optimization (PSO). These AI-driven optimization techniques hold great promise in advancing engineering processes by efficiently solving complex optimization problems.

One example of fault detection using LSTM deep neural network at Edge is presented inFigure11.

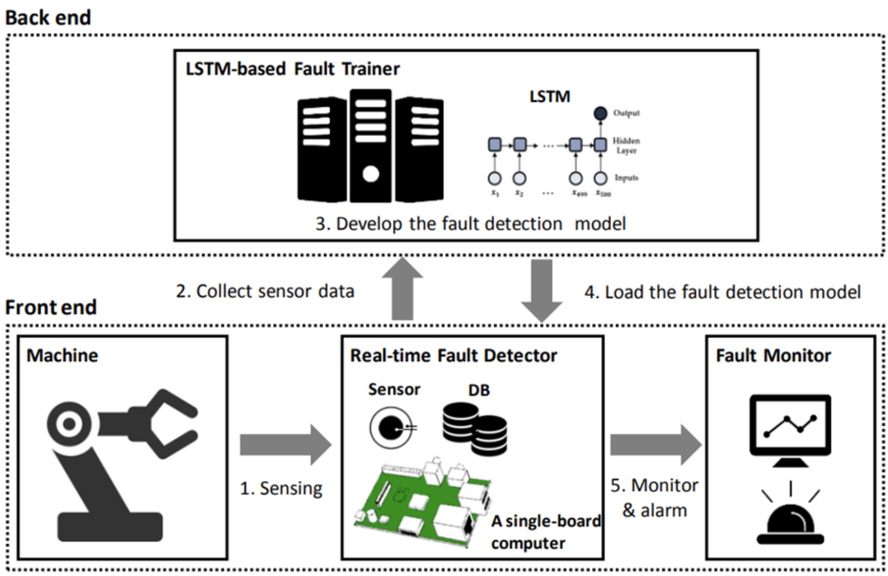


Figure 11. Example of fault detection using LSTM at Edge [52]

5. Edge AI Applications

The advancement of Edge Computing (EC) methodologies, encompassing robust IoT data, edge devices, storage, wireless communication, as well as security and privacy measures, has opened up opportunities for executing AI algorithms at the edge[53]. Edge Intelligence (EI) involves AI techniques such as machine learning, deep learning to enable intelligent data analysis and autonomous decision-making at the edge. The diverse applications of EI, like real-time video surveillance, autonomous vehicles, industrial automation, smart healthcare systems, and Internet of Things (IoT) devices are presented in Figure 12.

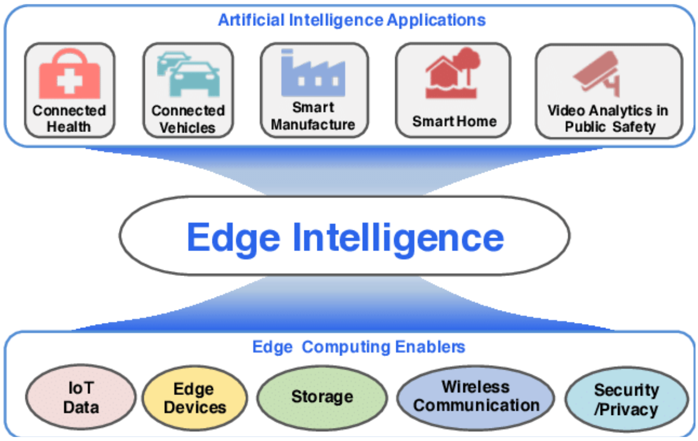


Figure 12. Edge Intelligence [53]

- *Autonomous Vehicles.* Edge AI is crucial for real-time decision-making in autonomous vehicles. It enables on-board perception, object detection, and collision avoidance by processing sensor data locally, ensuring quick response times and reducing dependency on cloud connectivity[54].
  An example of AI Edge solution for autonomous vehicle perception and control is presented at Figure 13. The partial end-to-end approach and end-to-end approach use deep neural network (DNN) for the final actuator output prediction [55].

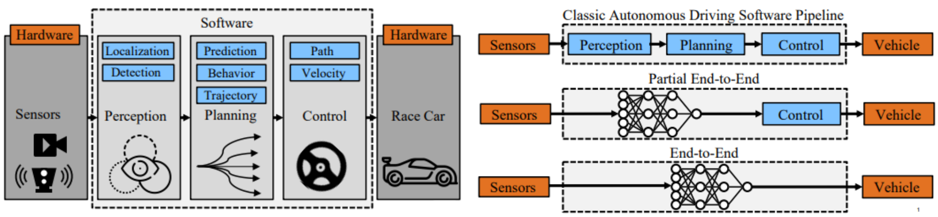


Figure 13. a). Example of autonomous vehicle AI Edge solution; b). Classic autonomous driving software pipeline in comparison to partialand full end-to-end software pipeline [55].

- *Smart Homes.* Edge AI allows smart home devices to perform voice recognition, natural language processing, and activity recognition locally. It enables faster response times, enhanced privacy, and local automation of various tasks within the smart home ecosystem [36].In tomorrow's smart home, for example, loaded with artificial intelligence, the cameras could identify people and intrusion detection. Smart home Edge AI devices become faster, responding instantly to user commands and providing real-time information. These quicker response times could be life-saving like door locks with instant facial recognition or smart induction stoves that automatically change cooking temperature for smart home devices that contact emergency services or raise alarms [56]. Other examples may seem more futuristic. A refrigerator that can provide suggestions of what to make for dinner based on contents within the fridge. An oven that can tell you when your meal is cooked to perfection. A virtual personal home yoga trainer that can remind you to straighten your arms during a pose.

- *Industrial Automation.* Edge AI plays a vital role in industrial automation applications, such as predictive maintenance, quality control, and robotics. It enables real-time analysis of sensor data, anomaly detectionand autonomous decision-making at the edge, improving operational efficiency and reducing downtime[57]. One example of hydraulic system fault detection based on LSTM neural network via Edge Computing is presented in Figure 14.

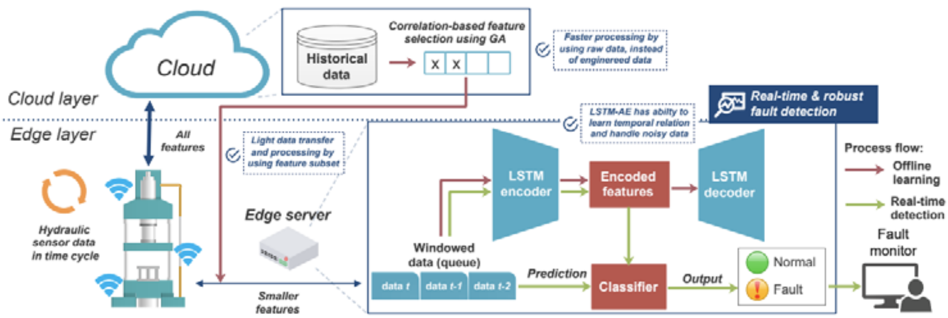


Figure 14. Example of Edge AI industry application [28]

- *Healthcare Monitoring.* Edge AI enables real-time monitoring and analysis of health data from wearable devices, such as heart rate monitors or glucose sensors, as shown in Figure 15. It allows for immediate detection of abnormal patterns, personalized healthcare recommendations, and timely alerts for medical interventions[58-59].

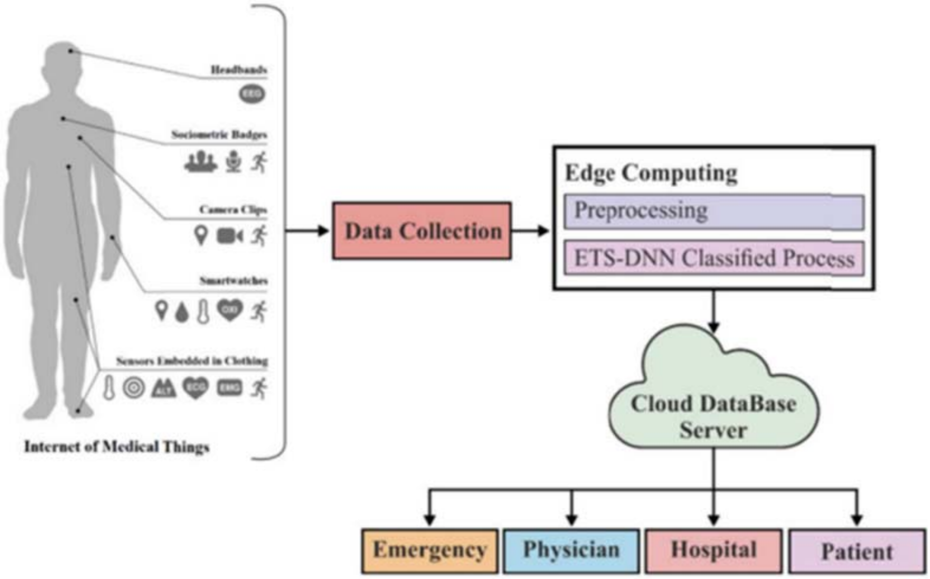


Figure 15. Smart healthcare with Edge AI solution [52]

- *Video Surveillance.* Edge AI is utilized in video surveillance systems to perform real-time object detection, tracking, and behavior analysis. It enables efficient video analytics at the edge, reducing bandwidth requirements and improving overall system performance[60]. An example of Edge AI camera application is presented in Figure 16.

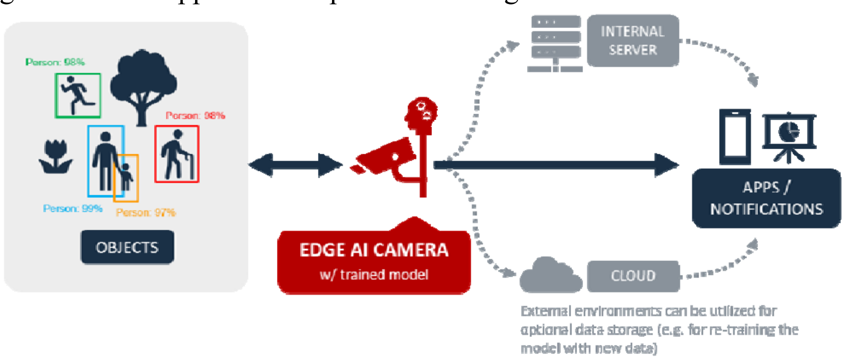


Figure 16. Example of Edge AI camera application [60]

- *Smart Cities.* Edge AI computing plays a crucial role in the development of smart cities. Sensors and cameras deployed throughout the city can collect data on traffic patterns, energy consumption, air quality, and more. Local edge servers can process this data to enable smart real-time traffic management, environmental monitoring, and resource optimization.A real-time deep lane detection system based on CNN Encoder-Decoder and Long Short-Term Memory (LSTM) networks for dynamic environments and complex road conditions is presented in [34].

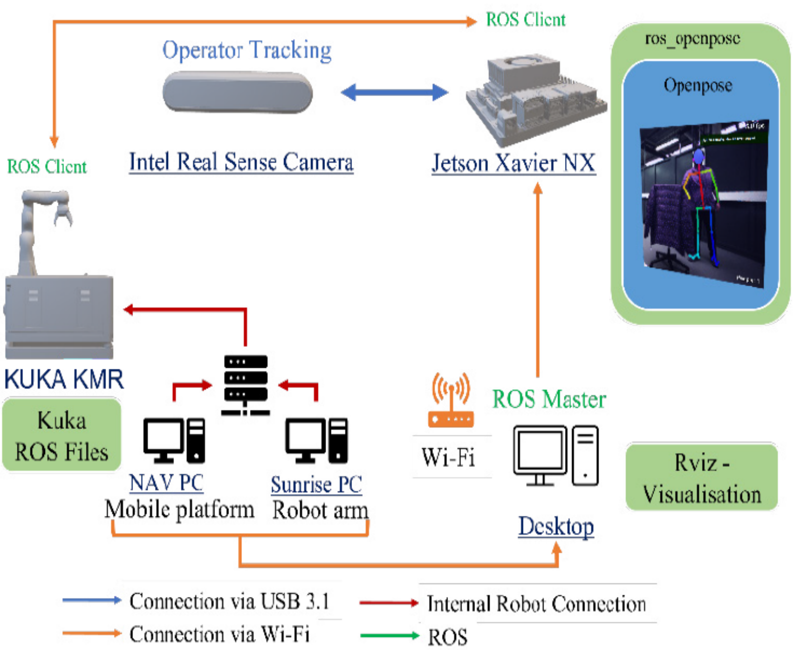


Figure 17. Overview of the integration of edge AI architecture for Collaborative Mobile Robots (CMR)[64]

- *Human-Robot Collaboration.* Edge AI plays a crucial role in enabling human-robot collaboration applications by bringing AI capabilities directly to the edge devices and robots involved in the collaboration. It allows robots to analyze and process data in real-time, make intelligent decisions, and interact with humans efficiently, without relying heavily on cloud resources. In human-robot collaboration scenarios, edge AI facilitates various aspects, such as perception, decision-making, and interaction. For example, edge AI algorithms deployed on robot platforms can enable real-time object recognition, tracking, and gesture recognition, enabling robots to understand and respond to human commands and actions. This enhances the safety and efficiency of human-robot interactions[14, 61-63].The integration of edge AI architecture for Collaborative Mobile Robots (CMR) is presented in Figure 17.

The following table presents the most popular devices for edge AI applications.

Table 1. Comparison of various devices for Collaborative Mobile Robots (CMR) [64]

Device	GPU	CPU	Memory
Nvidia Jetson Xavier NX	384-core NVIDIA Volta	2-core (1900MHz at 15W)	8 GB LPDDR4x
Nvidia Jetson Nano	128-core NVIDIA Maxwell (472 GFLOPs)	4-core Ctx.A57 (1.43 GHz)	4 GB LPDDR4
Raspberry Pi 3B	None	4-core Ctx.A53 (1.2 GHz)	1 GB LPDDR2
Google Edge TPU	Vivante GC7000(32 GFLOPs)	Cortex-A53 (1.5 GHz main CPU)	1 GB LPDDR4

Furthermore, edge AI enables robots to make autonomous decisions based on local data processing. By deploying machine learning models directly on the robots, they can perform tasks such as task planning, navigation, and path optimization without continuous reliance on cloud connectivity. This leads to faster response times and increased autonomy in human-robot collaboration scenarios.

Additionally, edge AI provides data privacy and security benefits. Keeping sensitive data and AI algorithms on the edge devices ensures that personal information and critical decision-making processes remain within the local environment, minimizing the risk of data breaches and maintaining privacy.

The connection between Edge AI and Industry 4.0 and Industry 5.0 is a powerful synergy that holds immense potential for transforming the manufacturing landscape.

Edge AI plays a crucial role in enabling the realization of the Industry 4.0 vision by bringing AI capabilities to the edge of the network, closer to the industrial devices and machinery. One of the key advantages of Edge AI in Industry 4.0 is real-time data analysis and decision-making. By deploying AI algorithms directly on edge devices within the industrial environment, data can be processed and analyzed instantly, leading to faster response times and improved operational efficiency. This enables proactive maintenance, predictive analytics, and optimization of manufacturing processes, leading to reduced downtime, enhanced productivity, and cost savings. The edge devices like robots can perform intelligent tasks and make autonomous decisions without relying on a centralized cloud or network connection. This distributed intelligence allows for greater flexibility, scalability, and resilience in the face of network disruptions, latency issues, or security concerns. Moreover, Edge AI enhances data privacy and security in Industry 4.0 applications. This is particularly crucial for industries dealing with proprietary designs, trade secrets, or compliance regulations[65-67].

The combination of Edge AI and Industry 4.0 also enables edge-to-cloud integration. While Edge AI empowers local decision-making and data processing, it can seamlessly connect with cloud-based platforms for broader analytics, machine learning model training, and centralized management. This hybrid approach leverages the strengths of both edge computing and cloud computing, creating a comprehensive and scalable architecture for Industry 4.0 applications.

Edge AI and Industry 5.0 are interconnected concepts that complement each other in the context of the evolving industrial landscape. Industry 5.0 emphasizes the collaboration between human workers and machines. Edge AI, with its ability to process data on the edge devices, facilitates seamless human-machine interaction by providing workers with contextual information and aiding them in complex tasks.Industry 5.0 creates more human-centric and sustainable production systems. Edge AI plays a critical role in enabling Industry 5.0 by bringing AI capabilities directly to the manufacturing floor. This allows workers to receive real-time feedback, make faster decisions, and respond to changing conditions promptly, thus leading to more efficient and flexible manufacturing systems[68].

The amalgamation of Edge AI and Edge Computing in the next-generation Industry 5.0, bolstered by 5G networks, presents significant opportunities across various sectors, including manufacturing, healthcare, Mobile Edge Computing (MEC), and smart cities. This technological advancement empowers industries to harness real-time intelligence, process data at the edge, and create intelligent, responsive systems that amalgamate the strengths of AI algorithms with the agility and low-latency capabilities of edge computing infrastructure[69-70].

6. Conclusion

Edge computing has gained significant traction in recent years due to its ability to process data closer to the source, reducing latency and improving efficiency.Edge AI techniques play a vital role in enabling intelligent decision-making at the edge devices themselves. The concepts of ‘’edge’’ and ‘’intelligence’’ are merely parts of a comprehensive solution that encompasses faster data processing, increased autonomy and transparency in operations, and a more agile and adaptable enterprise.

Edge AI and Industry 4.0 are intricately linked, with Edge AI serving as a catalyst for intelligent, decentralized, and autonomous systems in the manufacturing domain. This integration brings real-time analytics, local processing, enhanced security, and edge-to-cloud connectivity, enabling smart factories, predictive maintenance, and optimized industrial operations. By leveraging the potential of Edge AI within Industry 4.0, organizations can unlock new levels of efficiency, productivity, and innovation in the manufacturing landscape.

The future of Edge AI is expected to be dynamic and transformative, as it continues to evolve and address various challenges. As edge computing becomes more prevalent, there will be continuous improvements in edge devices' hardware capabilities. This will lead to more powerful and energy-efficient processors and dedicated accelerators designed specifically for AI workloads.The demand for edge AI chips has experienced significant growth, and the market is projected to witness substantial expansion in the coming years. Edge AI and cloud computing will collaborate more seamlessly, creating a hybrid ecosystem where data and processing are dynamically distributed between edge devices and centralized cloud servers. This synergy will allow for more efficient and scalable AI applications.

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Representation of Industry 4.0 Technologies in the Economy and Education of the Sarajevo Canton

Mirha Bičo Ćar[*1], Savo Stupar[1], Munira Šestić[1], Elvir Šahić[1], Isak Karabegović[2]

Abstract: *Since the introduction of the concept of Industry 4.0 until today, the world is facing a series of changes resulting from intensive scientific, technical and technological innovations. Research, innovation and development changes are aimed at improving production, business and everyday life through the application of basic technologies of Industry 4.0. In order for individuals, organizations, communities and states to be able to use the benefits of these improvements, it is necessary to rapidly adapt to all innovative trends: developing the necessary skills of individuals and groups for the adoption and use of these technologies, the implementation of technologies in companies, organizations and institutions, and the development of appropriate strategies that these processes would be managed and directed. In the developed world, these I 4.0 implementation processes are already reaching their maturity: educational programs are adapted to the needs of monitoring technical-technological changes, companies deal with solving challenges related to these processes after the implementation of Industry 4.0 technologies, and states and communities are working on devising further directions of development and a strategy that will further accelerate changes. In Bosnia and Herzegovina, the processes are somewhat slower: educational programs partially follow the needs of education for Industry 4.0, companies struggle with the challenges of adopting and implementing Industry 4.0 without adequate institutional support, and strategies related to exploiting the opportunities of Industry 4.0 have not been developed, both due to the lack of initiative, as well as due to administrative restrictions related to the complex political system of Bosnia and Herzegovina. Considering that, this paper presents the results of research on the representation of Industry 4.0 technologies in the economy and education of Sarajevo Canton. The sample on which the research was conducted included 105 companies and 239 respondents from the general population. The results show that the highest level of application of Industry 4.0 technologies exists in the part related to the advanced management of company resources using planning and management support systems, and in communications. These findings, as well as the results related to the established level of knowledge of Industry 4.0 technologies in the general population, speak in favor of the need for the urgent development of various educational programs that will accelerate the learning of Industry 4.0 among all members of the community, as well as the establishment of state programs to support the implementation of technologies in companies, so that the economy of the Canton and the country as a whole would not fall behind in relation to the world driven by the fourth industrial revolution.*

[*1]University of Sarajevo, School of Economics and Business, Trg oslobođenja 1. Sarajevo
[2]The Academy of Sciences and Arts of Bosnia and Herzegovina, Bistrik 7. Sarajevo
E-mail: mirha.car@efsa.unsa.ba

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1. Introduction

From the first appearance of the term Industry 4.0 at the fair in Hannover in 2011, until today, we are witnessing numerous changes related to Industry 4.0, which are present at all levels: from new skills and knowledge of individuals, through the way of doing business and production in companies, to strategic thinking at the level of wider communities.

Industry 4.0, as a phase in production-business and social development, is based on automation (specific to the previous one, Industry 3.0), and numerous disruptive novelties based on information and communication technologies (ICT), cyber-physical systems (CPS), and their high connection with operational technologies (OT) when performing production and business activities.

In 2015, the Boston Consulting Group [1] identified 9 technologies as the fundamental technologies of Industry 4.0, and these technologies were named ‘’the nine pillars of technological advancement’’ [1]. In the meantime, the list was expanded [2], so that today the authors list a significantly larger number of fundamental technologies that support the functioning of Industry 4.0 [3].

Bearing in mind the number of new technologies included in Industry 4.0 and their complexity, it is clear that the successful application of Industry 4.0 technologies and the implementation of Industry 4.0 in business and production require both the acquisition of missing software, hardware and other necessary material resources, but also imply adequate training of employees for acceptance, implementation and application of the mentioned technologies. Although it is usually about user-friendly technologies that are used by a large number of people in everyday life to a certain extent, full utilization of the opportunities and benefits offered by the application of these technologies in production and business requires adequate training of employees, which can only be achieved with appropriate education programs in systems of formal and informal education and training at the workplace.

Considering the above, this paper will present the characteristics of Industry 4.0, its fundamental technologies and ways of using them in business and production as well as the key effects produced by Industry 4.0 in companies that use it. Data on the representation of Industry 4.0 technologies in the Sarajevo Canton in the economy will also be presented, as well as the understanding of Industry 4.0 and its technologies among the general population, as a reflection of the representation of Industry4.0 technologies program in educational programs of secondary and higher education in the Sarajevo Canton.

2. Fundamental technologies of Industry 4.0: application and implementation in business

Industry 4.0 and its fundamental technologies are the result of scientific-technical-technological development of the last 30 years in the domain of mechatronics, robotics, electrical engineering, computer science, artificial intelligence, sensors, chips, but also business administration, and business and information systems engineering. Thanks to the constant improvements of existing technologies, but also the ‘’emergence’’ of new ones, from the ‘’initial’’ five basic technologies (Cloud Computing, Big Data, Additive Manufacturing, BlockChain, Sensors), today we have reached the number of several dozen technologies that support the functioning of Industry 4.0 [3]. Nevertheless, among practitioners and theoreticians of Industry 4.0, 9 to 11 fundamental technologies are most often discussed in accordance with the identification offered by the Boston Consulting Group in 2015 (which include: additive manufacturing - 3D printing, autonomous and collaborative robots, Big Data, cloud computing, horizontal and vertical connection of systems, industrial Internet of Things, cyber security, simulations and augmented reality) [1]. In their operation, these technologies enable completely new ways of functioning of economic and everyday life, as described in Table 1 and Figure 1 [2].

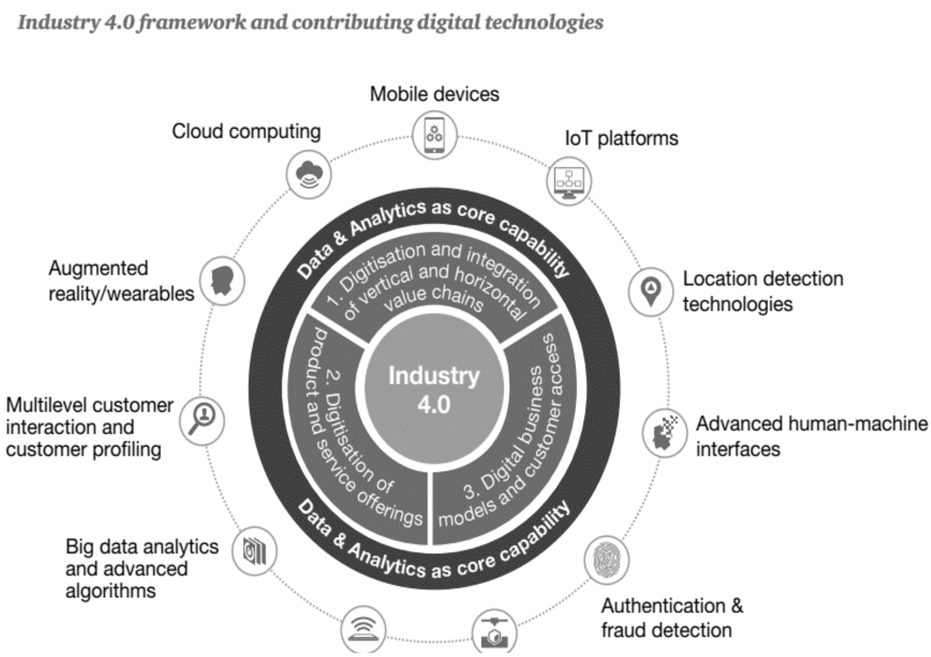

Figure 1. Industry 4.0 framework and contributing digital technologies [2]

Table 1.a. Industry 4.0 technologies and their application in business and industry (source: authors as cited)

Technology	Examples of application of Industry 4.0 Technologies
Additive manufacturing - 3D printing	Additive manufacturinginvolves the production of objects by applying thin layers of particles that bind together and thus build the desired shape. Construction of objects is done on the basis of a three-dimensional model (previously prepared using a CAD program or by three-dimensional scanning of an existing object that is to be ‘’copied’’). Additive manufacturing - 3D printing is applicable in all industrial branches for rapid production of prototypes, spare parts, new products, and even highly precise tools, while reducing costs related to testing. 3D printing has also found enormous use in the medical industry for the production of prostheses, implants, and even organs.[4]
Autonomous and collaborative robots	Autonomous robots are designed and built so that they can perform assigned tasks in a certain time, independently and without any human intervention to guide them. They are equipped with sensors and other elements that allow autonomous robots to monitor the environment and adjust according to possible changes in conditions. Collaborative robots work in physical interaction with humans in a shared workspace. Collaborative robots are also teleoperation robots that can be controlled ‘’remotely’’ via a wireless network, which is suitable for extreme situations and conditions.[4, 5]
Big Data	Big Data technology, based on Hadoop systems, enables the processing of large amounts of data in real time from various sources (instead of sample analysis). They are used by large trading and marketing companies to monitor and analyze consumer behavior and identify patterns of behavior to create optimized individual offers. In the banking industry, Big Data technology enables risk management, detecting fraud patterns, increasing customer satisfaction, etc. [6]
Cloud Computing	Cloud Computing enables computer data processing to be performed and billed as a service with the adaptability of IT system capacity to changing needs and the minimization of costs and expenses related to those adaptations. [7] Examples of commercial applications of Cloud Computing are: Amazon Elastic Compute Cloud, which provides users with access to a multitude of virtual devices, instance types, operating systems, and software packages through a network interface; Amazon Simple Storage Service (Amazon S3) that allows storing any amount of data downloaded from the Internet, regardless of location or time [8, 9]; Similar services are offered by Google, one of the leading providers of cloud computing services that provide end users with the possibility of secure data storage. [10]

Table 1.b. Industry 4.0 technologies and their application in business and industry (source: authors as cited)

Technology	Examples of application of Industry 4.0 Technologies
Horizontal and vertical connection of the system	Horizontal and vertical system integration is enabled and facilitated by the application of advanced and intelligent MRP and ERP systems based on machine learning and advanced analytics [4]. Namely, horizontal integration represents a business expansion strategy, in which the company creates a business line at the same level of the value chain, whereby the company uses its available resources. Example: Apple transferred its knowledge and experience in the production of mobile phones to the production of iPad tablets. Vertical integration is the expansion of activities into the previous or subsequent ‘’links’’ of the supply chain (expansion in the activities of suppliers or customers) [11], where as an example we can again take Apple, which in the production of smart phones, notebook computers, etc. controls the entire flow of production and distribution, from beginning to end. Both vertical and horizontal integration make the organizational structure so complex that monitoring and management require the support of systems such as intelligent MRP and ERP.
The Industrial Internet of Things (IIoT)	The Internet of Things (IoT)represents the connection of objects (devices or things) via the Internet (most often wireless) in which physical and virtual ‘’things’’ of all kinds exchange data and are invisibly integrated. Such integration creates new possibilities of control, monitoring and provision of advanced services [12]; The Industrial Internet of Things (IIoT) implies the monitoring of complete production in all aspects, with the possibility of application in all industries. Supervision is performed by a central workstation that monitors products, product parts, production techniques and environmental conditions via radio frequency, which it recognizes using assigned identification codes (for material elements in the system) and various sensors (for monitoring environmental conditions).[4]
Extended Reality: aR, AR, MR, VR	Extended Reality (XR) includes the four technologies Assisted (aR), Augmented (AR), Mixed (MR) and Virtual Reality (VR). XR combines the physical world with the ‘’world of digital twins’’ allowing their proper ‘’interaction’’ [13], Assisted Reality provides support in performing daily tasks by using appropriate devices (lenses, glasses, helmets, etc.) and providing relevant information in the immediate field of vision of the support user. Augmented reality is a version of the tangible real world supplemented and improved with digital information: visual elements, sound or other sensory stimuli based on modern technologies. Mixed Reality represents a combination of the real and virtual worlds, Virtual Reality - enables a digital experience, completely isolated from physical reality.[14]

Table 1.c. Industry 4.0 technologies and their application in business and industry (source: authors as cited)

Technology	Examples of application of Industry 4.0 Technologies
Extended Reality: aR, AR, MR, VR (cont.)	For example, AR supports the sale of consumer goods and services so that customers can get an idea of the product's features; in the regular work of the company in the maintenance of complex systems and for other purposes, up to medical interventions where it provides support to doctors through data necessary for the successful performance of medical procedures.[15]
Cyber security	Cyber security is a complex system of measures, activities, procedures and protocols to prevent malicious activities that can cause damage to one or more elements of the information system. [16, 17] The most common sources of malicious activity are: Ransomware (uses encryption to attack the target and force them to pay a ransom demand) [18], Mobile Malware (targets mobile devices and private content accessible via mobile devices) [19]; Infostealers (software that steals sensitive data from infected devices and sends it to the malware operator) [20], Banking Trojans: Malware that targets financial data and attempts to steal banking website logins and similar data [21]. It is clear that without appropriate cyber security measures, the functioning of I 4.0 technologies and smart factories based on cyber-physical systems is not possible.
Simulations	A digital twin is a virtual (digital) copy of a physical object. This technology is used to predict the behavior of products and systems at different stages of their life cycle (from design and planning, through construction, work and operations, to optimization and maintenance) as follows: predicting the behavior of complex systems; simulation of complex systems; interoperability - extracting data in complex systems, performing asset maintenance activities, both for carrying out repairs and for preventing breakdowns; visualization of complex systems during ''work''; product simulation during the ''design and manufacture'' phase. [22]

Based on Figure 1 and Table 1, it is evident that in a mutual combination of the listed technologies of Industry 4.0, they enable completely new ways of organization, implementation and management of industrial value chains, which are based on [23]:

''Data, computational power, and connectivity - based on blockchain, cloud computing, sensors and Internet of Things;

Analytics and intelligence - based on machine learning and artificial intelligence;

Human - machine interaction: collaborative robots - cobots, augmented reality, virtual reality, autonomous guided vehicles;
Advanced engineering: additive manufacturing and renewable energy'' [23, 24].
Bearing in mind the described specifics, the opportunities it provides and the key effects produced by Industry 4.0 and its technologies, Industry 4.0 can be defined as the complete digitization and automation of the business-production system, including the digitization of value chains that (all together) enable the communication of products, services, economic entities and the economic ecosystem as a whole.[2; 25: p. 240; 26; 27]
The successful implementation of Industry 4.0 in business and production implies the provision of missing software, hardware and other necessary material resources (which require significant financial expenditures), but also the ''equipment'' of employees with adequate knowledge and skills so that they can successfully meet the demands of jobs in the working environment characteristic of Industry 4.0. This means that companies and organizations should enable employees to improve and requalify (upskilling and reskilling), but also engage in finding candidates/future employees who possess the knowledge needed to use I 4.0 technologies[24]. For appropriate education and training of employees to master the technologies of Industry 4.0, appropriate programs for education on the technologies of Industry 4.0 are needed both within organizations and companies, as well as within public education systems.
Developing educational programs for Industry 4.0 implies appropriate curricula and programs within the formal education system, as well as strategies for successful implementation of goals, including sufficient financial resources and appropriate financial management, qualified personnel, partnership with business entities, advanced infrastructure, and effective workshops. Additionally, researchers emphasize the importance of developing practical expertise and implementing digital technologies to empower startups with the necessary skills and competitive advantage for Industry 4.0 [28]. Research conducted through a detailed review of the literature shows that augmented and virtual reality, simulations and the Internet of Things are present to a greater extent in current educational programs, as well as that these programs are more often related to university educational programs than to secondary school education programs [29].

3. Benefits of using I 4.0 technologies in companies

Despite the challenges related to the implementation of Industry 4.0 technologies, the benefits promised by the use of Industry 4.0 technologies in everyday business are a key argument for the accelerated introduction of these solutions in all business functions and activities. In general, the majority of authors state the following benefits: increased productivity (both labor productivity, due to increased production speed, and multifactorial productivity due to more rational use of resources), increased production flexibility due to the flexibility of machines, increased speed of product development due to the application of 3D printing, simulations and digital twins, and increased control due to the use of sensors and real-time monitoring, which ultimately results in reduced costs, increased profits and increased customer satisfaction.[4].

Taking into account the described characteristics of Industry 4.0 technologies, the consulting company McKinsey estimated that it is possible to expect significant improvements in various aspects of the performance of the business-production system, such as [30]:

‘’15 – 20% inventory holding cost reduction;
15 – 30%labor productivity increase;
30 – 50% machine downtime reduction;
10 – 30% throughput increase,
85% forecasting accuracy improvement,
10-20 % cost of quality improvement’’[24].

In addition, it is estimated that the application of Industry 4.0 technologies could generate values for manufacturers and suppliers of 3.7 trillion dollars in 2025 [30].

Although companies are aware of the numerous benefits that they can achieve by applying Industry 4.0 technologies, nevertheless, due to high costs, as well as other difficulties and challenges related to the implementation of Industry 4.0 technologies, companies usually implement individual technologies, which are available to them, taking into account the available financial and other resources. Even then, when only certain technologies are applied, the effects that are achieved are significant. Thus, research conducted in Brazil based on data from 2016 [31], showed that the implementation of certain Industry 4.0 technologies provides significant benefits in terms of individual company performance. The performed analyses determined that a positive and statistically significant influence ‘’on product characteristics, in terms of the level of customization, product quality and the speed of launching new products, has integrated engineering systems for product development and manufacturing, incorporation of digital services into products, additive manufacturing and Cloud Services, while Big Data analysis showed a negative impact on product-related elements. Furthermore, CAD/CAM, digital automation with sensors for process control and Big Data showed a positive impact in relation to the internal industrial activity of the factory: costs, productivity and process control, while additive manufacturing showed a negative impact on internal industrial activity. Finally, the positive impact of additive manufacturing on side effects, which include the improvement in sustainability (or reduction of externalities) and the reduction of labor claims'' [31]was determined. Analyses carried out in Italy [32], on over 900 companies monitored over a long period of time, showed a 7% increase in labor productivity based on the introduction of Industry 4.0 technologies, with better effects in the case of the introduction of two technologies (compared to the introduction of only one Industry 4.0 technology), greater positive effects in the case of the introduction of production technologies in high-tech companies and better effects from the introduction of customization technologies in low-tech companies, and a delayed positive impact of data-driven technologies on labor productivity in low-tech firms. This research also determined that the positive effects of the recorded increase in productivity decrease over time [32].

The implementation of Industry 4.0 in business is one of the key topics in the modern world, so, in order to make the most effective use of all the benefits promised by Industry 4.0 technologies, governments around the world are defining strategies for the accelerated implementation of I 4.0 in the economy and business [33, p. 54.]. Unfortunately, such organized activities to define a strategy for the adoption and implementation of Industry 4.0 technologies in the economy of Bosnia and Herzegovina are missing [34: p. 57, 80, 125], and the implementation activities of Industry 4.0 technologies are mostly based on the initiative of businessmen and managers through development strategies of individual companies. Considering all the above, it is important to identify the level of representation (and utilization) of Industry 4.0 technologies in companies in Sarajevo Canton, but also the understanding and knowledge of this phenomenon among managers, employees and the general population. In addition, it is necessary to determine the extent to which educational programs give importance to technologies and Industry 4.0, and to examine the understanding of this term and concept among pupils and students, participants in the education system in Sarajevo Canton.

4. Industry 4.0 in the Economy and Education of Canton Sarajevo

4.1. Ecosystem of the Sarajevo Canton economy

Sarajevo Canton is one of the ten cantons in the Federation of Bosnia and Herzegovina and the institutional center of the country. Sarajevo Canton is home to the capital city, the most important state and federal institutions as well as international institutions and organizations. Canton Sarajevo is one of the smallest cantons in the Federation of Bosnia and Herzegovina by area, with only 4.9% of the area it occupies in the Federation, but in terms of the number of inhabitants it leads in comparison to other parts of the country and cantons, with a total of 419,543 inhabitants [35, p. 23], i.e., 328.6 inhabitants/km^2 according to the data of the Federal Bureau of Statistics from 2022 [35, p. 14].

Table 2. The most important economic parameters for the Sarajevo Canton - 2020.[authors, according to: 36, p: 29, 36, 37, 43]

	Description of activity	Companies %	Employed %	Structure of investments %	Net Profit %
A	Agriculture, forestry	1%	0,7	0,2	0,2
B	Mining	0%	0	0	0,2
C	Processing industry	**8%**	**9,3**	6,5	**18,2**
D	Electricity production	1%	1,3	**16,4**	1,7
E	Water supply, sewerage, waste	0%	1,7	1,3	0,5
F	Construction	7%	4,8	**9,2**	5,3
G	Trade	**29%**	**18,9**	**12,9**	**29,7**
H	Transport and storage	4%	5,3	5,4	3,5
I	Provision of accommodation, preparation and food serving	5%	6,1	2,9	0,4
J	Information and communication	7%	6,6	8,9	**14,2**
K	Finance and insurance	1%	4,3	5,9	1,7
L	Real estate business	**8%**	1,4	4,9	3,2
M	Professional, scientific and technical activities	**17%**	5,7	1,4	**14,3**
N	Administrative and auxiliary service activities	7%	4,4	2,7	2,8
O	Public administration and defense	0%	**10,7**	**13,3**	0
P	Education	2%	7,3	2,2	0,7
Q	Health and social care	1%	6,6	2,8	2,9
R	Arts, entertainment, recreation	1%	2,0	1,1	0,1
S	Other service activities		3,1	1,5	0,2
	Households		-	0,6	-
	Total:	100%	100%	100%	100 %

A large part of the employees in the Federation of Bosnia and Herzegovina is concentrated in Sarajevo Canton. With 152,576 employees in 2021 [36, p. 27], the Sarajevo Canton ‘’gathers’’ as much as 28.5% of the total number of employees in the Federation of Bosnia and Herzegovina, and the economy of the Sarajevo Canton generates about 32% of the gross domestic product of the Federation of Bosnia and Herzegovina, which in 2022 amounted to over 25.2 billion KM.
More than 40,000 economic entities operate in the area of Sarajevo Canton *[34, p. 37]*, of which 7,720 entities manage accounting in accordance with the accounting framework for economic companies (of the 25,270 that operated in the Federation of Bosnia and Herzegovina in 2022)*[37, p. 7]*.

Among economic entities, the most numerous are those from the tertiary sector of service activities with 4190 entities, i.e., 54.3%.Observed by activity, the largest number of economic entities is in trade, with more than 29.3% of enterprises, and in M activities - professional, scientific and technical activities, with a share of 16.9% [36, p. 37]. Most of the employees in Sarajevo Canton engage in the following activities: G - wholesale and retail trade, O - public administration and defense; C – processing industry; J - information and communications, P - education and Q - health and social care [36, p. 29].

The largest investments are related to the production and supply of electricity - 16.4%, construction - 9.2%, trade - 12.9% and public administration and defense, 13.3%. [36, p. 36]. The value of investments in 2020 amounted to 1 billion and 29 million KM, of which most investments were directed to construction works and transfer of ownership, (in both cases with growing investments of 18.9% and 197.4% more than the previous year, respectively). Investments in machinery, equipment, means of transport 40%, and other assets (intangible fixed assets and other tangible assets)make 9% of the value of total investments [36, p. 35-36].

The net profit achieved in 2020 in Sarajevo Canton was 974 million KM. The largest participation in the generation of net profit is held by trade with 29.7% of the realized net profit, followed by the processing industry with 18.2%, professional, scientific and technical activities with 14.3%, and information and communication activities with 14.2%.

All these data tell us about the impact of certain activities on the economy of the Sarajevo Canton, but also which activities could first invest in Industry 4.0 technologies. It is reasonable to expect that the last four listed activities (trade, processing, ICT and professional, scientific and technical), with the conditions they possess (which are linked to higher levels of generated net profit) and the possibility of benefiting from the application of Industry 4.0 technologies, will be the initiators for adoption and implementation of Industry 4.0 technologies.

4.2. Education system in Sarajevo Canton

Adequate education is the basis for the successful development of a certain community and a prerequisite for adequate training of the populationfor appropriate inclusion in the business world. Bearing this in mind, it is necessary to look at the effects of the teaching and educational programs implemented in the education system of the Sarajevo Canton, which are in the function of education about modern technologies and ways of their application.

Table 3. Educational institutions in Sarajevo Canton and technical equipment with computers [authors according to: 36, p. 53-57]

	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022
Elementary school	97	97	100	100	100
Computers/pupils	17	20,5	20,3	19	17,4
Secondary schools	39	39	40	40	41
Computers/pupils	9,6	9,3	9,7	8,5	7,8
Higher education institutions	37	32	32	31	31

There are 92 elementary schools, 41 secondary schools, and 31 higher education institutions in Sarajevo Canton (according to data from the Institute for Development Planning of Sarajevo Canton for the school and academic year 2021/2022). All educational institutions are equipped with a certain number of computers and other information technology, which meets the needs of successful teaching, *[36, p. 53-57]*, and educational programs necessarily include IT education and training (Table 3).

Secondary schools and faculties of technical orientation carry out teaching and training related to the technologies of Industry 4.0. Additionally, as of 2018, in about 5% of primary and secondary schools in Sarajevo Canton, through inclusion in appropriate development projects, STEM classrooms were established, suitably equipped (robots, 3D printers, scientific kits, etc.) [38] In *addition, the teaching staff was also trained for teaching and training within the STEM program in elementary and secondary schools.*

Considering the above, Sarajevo Canton demonstrates that it provides conditions for adequate education of pupils and students about the technologies of Industry 4.0, but the question arises as to what it is like in reality, and how much the pupils and students in the Sarajevo Canton, as well as the general population, really know about the technologies Industries 4.0.

4.3. Learning and knowledge about Industry 4.0 in Sarajevo Canton

Research on the understanding, knowledge and perception of the impact of Industry 4.0 among young people, employees and the general population in Sarajevo Canton and the representation of Industry 4.0 technologies in companies in Sarajevo Canton was carried out (for both parts of the research) in the second half of 2022. The research, in accordance with the objectives, was divided into two parts: one, which was focused on identifying knowledge and understanding related to Industry 4.0 and I 4.0 technologies, and the second part, which was aimed at identifying the use of Industry 4.0 technologies in the economy.

Table 4a: Demographic characteristics of the respondents

Demographic variables	**N**	**%**
Total respondents:	**239**	**100%**
Gender:		
Male	88	36,8
Female	151	63,2
Achieved educational level:		
Schoolar	84	35,1
Secondary school	42	17,6
College - II years	13	5,4
University degree	42	17,6
Masters	36	15,1
Doctorate	22	9,2
Occupation:		

Data collection was done online and to a lesser extent through printed questionnaires distributed using the snowball method. The questionnaires used for data collection were developed for the purposes of this research, and according to the questionnaires used in similar, previously conducted research[39].

The research included 239 individuals (general population) and 105 companies for which data was provided by company managers.

Demographic characteristics of

Pupils /students	125	52,3
Workers/employees	67	28,0
Senior level manager	19	7,9
Lower and middle lever manager	13	5,4
Employer/owner	12	5,0
Pensioner	2	0,8
Unemployed	1	0,4

respondents from the general population sample are presented in Table 4. As can be seen from Table 4a, the sample included: men and women of different levels of education, with different occupations, from all administrative units (municipalities) from Sarajevo Canton.

Table 4b: Demographic characteristics of the respondents

Demographic variables	**N**	**%**
Age group		
16-20 years	115	48,1
21-30 years	34	14,2
31-40 years	36	15,1
41-50 years	24	10,0
51-60 years	22	9,2
61 +	8	3,3

The respondents belonged to different age groups, aged 16 to 66 years, with younger respondents dominating the sample, in order to get answers related to the knowledge of young people regarding Industry 4.0 technologies (Table 4b).

The questionnaire used to examine the representation of knowledge about technologies and Industry 4.0 contained a total of 17 questions. In addition to 7 questions related to the demographic characteristics of the respondents, ten more questions were offered that related to the understanding of the concept of Industry 4.0, the ways of acquiring knowledge about Industry 4.0, the representation of topics related to I 4.0 in formal educational programs, and the understanding of the potential impact of implementing Industry technologies 4.0 in the economy to jobs and future employment opportunities. The most interesting findings determined by the research are presented below.

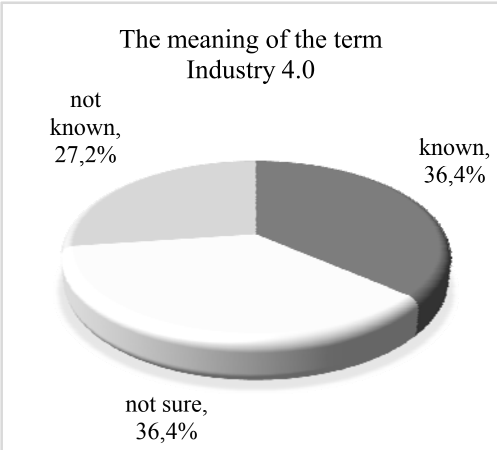

Figure 1. Understanding the meaning of the term I 4.0

The initial questions in the questionnaire oncerned knowledge and understanding of the term I 4.0. When asked about the meaning of the term I4.0, 36.4% respondents, i.e., 87 cases, answered that they know the meaning of the term Industry 4.0; 36.4% of respondents report that they do not know the meaning of the term, while 27.2%, or 65 respondents, are not completely sure of the meaning of the term Industry 4.0. (Figure 1)

Therefore, only a little more than a third of the total number of respondents included in the research know the content of the term Industry 4.0. Looking at the structure in the subgroups of respondents, this means: 34% of students, 13% of secondary school students, 40% of people in employment, and 68% of managers (from the number of respondents of the observed subgroup).

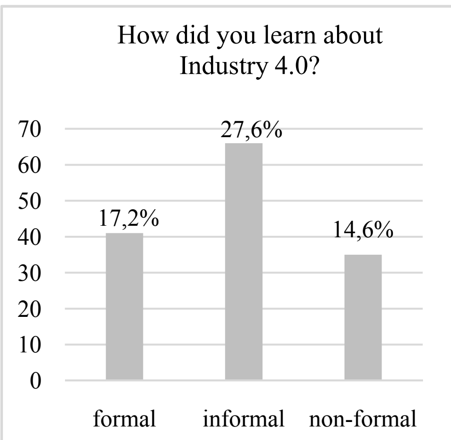

Figure 2. Learning about Industry 4.0

When asked about the method of acquiring knowledge about Industry 4.0, 66 respondents answered that they acquired knowledge through informal learning, that is, 27.6% of respondents in this group. In 17.2% of cases, i.e., 41 respondents, reported formal acquisition of knowledge about Industry 4.0, and 35 respondents, i.e., 14.6%, answered that they acquired knowledge about Industry 4.0 through non-formal education - through seminars, workshops, courses, etc. (Figure 2)

The next question in the questionnaire referred to the extent to which education about Industry 4.0 technologies is represented in formal education. To the question ‘’To what extent have you acquired knowledge about Industry 4.0 and the technologies it is based on during your education so far?’’, a large number of respondents answered in the negative. As much as 50% of respondents did not learn about these technologies through formal education, and only slightly more than 7% (17 respondents in total) answered that they learned about Industry 4.0 and Industry 4.0 technologies to a sufficient extent or a lot, as can be seen in Figure 3.

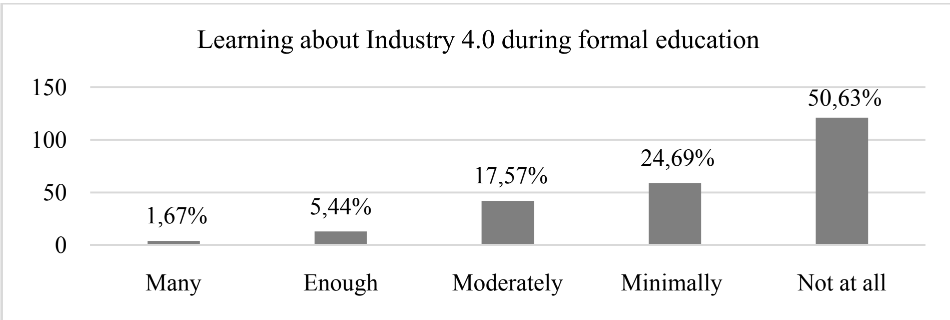

Figure 3. The scope of formal education about Industry 4.0

In the continuation of the questionnaire, the questions were aimed at examining the respondents’ perception of the impact that Industry 4.0 and its underlying technologies can have on the labor market. For the sake of a precise understanding of the term, a short interpretation of Industry 4.0 was stated in the questionnaire, and then questions were asked about the effect of Industry 4.0 on the generation of new jobs, but also the possible negative impact on the existing ones.

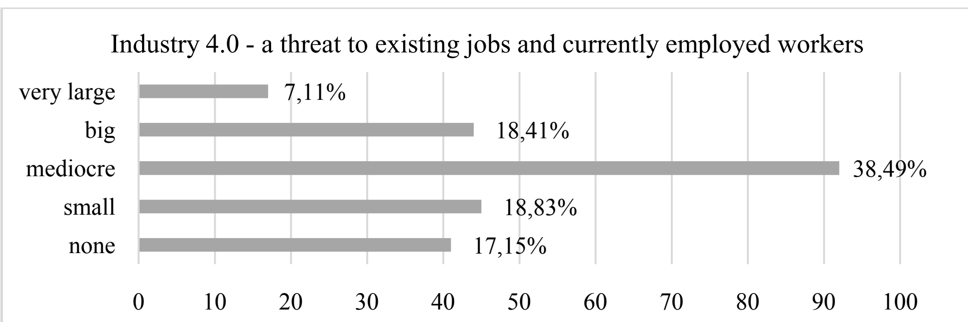

Figure 4. Perception of Industry 4.0 as a threat to existing jobs

More than 25% of respondents believe that Industry 4.0 is a big or very big threat to existing jobs, 38.5% of respondents think that this negative impact is moderate, while the remaining 36% of respondents think that Industry 4.0 does not represent a significant threat to existing jobs (i.e., that Industry 4.0 technologies pose little or no threat). At the same time, the vast majority of respondents recognize the potential positive impact of Industry 4.0 on the generation of new job positions and jobs. As can be seen in Figure 5, 87.87% of respondents believe that Industry 4.0 will have a positive impact on the creation of new job positions, while only 12% of respondents expect little or no impact of new technologies on the creation of new job positions.

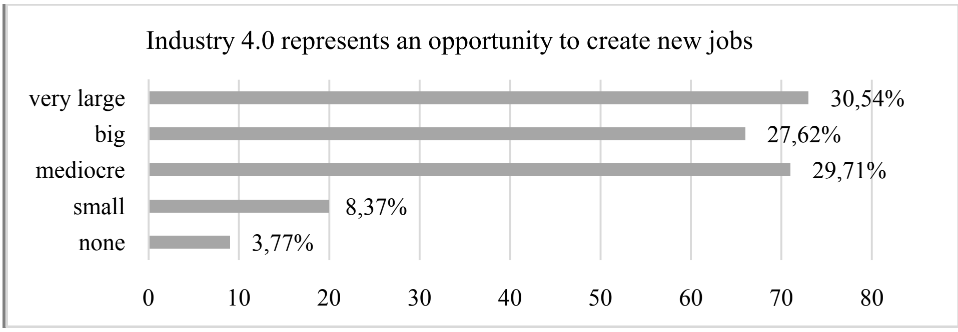

Figure 5: Perception of Industry 4.0 as an opportunity for new jobs

The described answers of the respondents speak of the insufficient knowledge of the general population when it comes to Industry 4.0 and its basic technologies, but also of the positive perception of the respondents in Sarajevo Canton about the impact of new technologies on the labor market. According to the answers given by the respondents, it can be concluded that the respondents expect the positive impact of new technologies to a much greater extent, compared to the potential negative impact in terms of endangering jobs. Furthermore, findings related to answers to questions about knowledge of Industry 4.0 technologies and the extent of formal education, can suggest two recommendations: the need to increase formal teaching content related to Industry 4.0 technologies, but also the need to develop adequate programs of informal education. Although formal education is the most effective way of disseminating knowledge, the fact that in the case of Industry 4.0 it is about new technologies, speaks in favor of the need to develop as many informal education programs as possible in order to spread knowledge about these technologies and the possibilities of their use in different branches and activities in order to be more distributed to the general population in Sarajevo Canton.

4.4. Representation of Industry 4.0 technologies in the economy of Sarajevo Canton

In order to complete the picture of the representation of Industry 4.0 technologies in Sarajevo Canton, the second part of the conducted research was focused on the application of Industry 4.0 technologies in companies in Sarajevo Canton. In this case, the interviewees were managers from the companies in the sample, and the sample included 105 companies.

Table 3a: Structure of the sample of companies

Demographic variables	**N**	**%**
Total respondents:	**105**	**100%**
Occupation:		
Senior level manager	27	25,7
Lower, middle level manager	57	54,3
Artisan	4	3,4
Employer/owner	17	17

As stated, the data in the research was provided by decision makers in companies: managers of different levels, entrepreneurs and business owners.As can be seen from Table 3b, the sample included companies of various sizes, from most economic branches and activities operating in Sarajevo Canton (excluding mining, water supply, health and administration - public).

Table 3b: Structure of the sample of companies

Demographic variables	**N**	**%**
Total respondents:	**105**	**100%**
Company size		
Micro (1-9 employees)	24	22,9
Small company (10 - 49)	20	19,0
Middle-large companies	29	27,6
Large companies (250+)	32	30,5
Type of production	**N**	**%**
Individual and small batch	36	34,3
Serial and large-batch	36	34,3
Modular production	22	21,0
Web product configuration	11	10,4

In the companies taken from the sample, the production of products and services takes place most often as individual and small-batch and serial and large-batch (in 34.3% of cases for both).

In 21% of cases, modular production is applied, and in 10% of cases, web configuration of the product is possible.

The next question in the questionnaire referred to the company's readiness for ''Industry 4.0''. Respondents' answers to this question were distributed almost normally (Figure 6). 30.5% of respondents believe that the company they work in is moderately prepared for Industry 4.0; 42% of respondents believe that the company is sufficiently or significantly prepared for Industry 4.0, while 29.5% of respondents consider the company they work in to be insufficiently prepared for I 4.0, of which 3.8% of respondents rated this preparedness as completely insufficient.

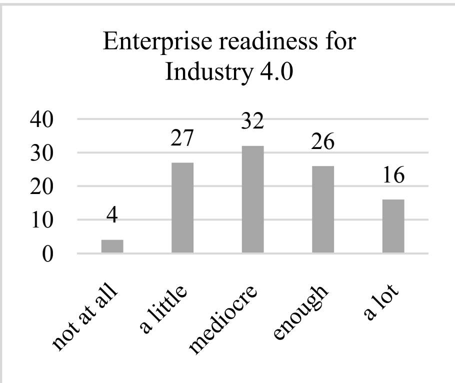

Figure 6: Company readiness for Industry 4.0.

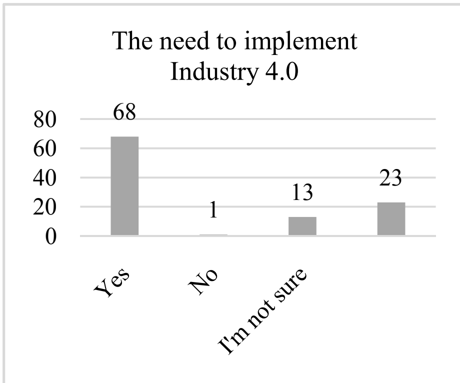

Figure 7: The need to introduce Industry 4.0 technologies

The respondents' perception of the need to implement Industry 4.0 technologies in companies in Sarajevo Canton is in accordance with the assessment of the readiness for the introduction of Industry 4.0 technologies. 64.8% of respondents believe that there is a need for the introduction and application of Industry 4.0 technologies in business and production processes, and 34.3% of respondents are not sure or believe that the implementation of Industry 4.0 technologies depends on and should be adapted to the trends in the environment. Only one participant in the research believes that there is no need to implement Industry 4.0 technologies (Figure 7).

The following questions examined the current situation with the representation of certain Industry 4.0 technologies in the business and production processes of companies in Sarajevo Canton- The questions concerned the technologies used for the development of products/services, the way of communication in companies, the use of industrial robots, the use of composite materials, the use of additive manufacturing and the application of software programs for decision support.

As can be seen in Figure 8 (below), Industry 4.0 technologies are used in as many as 66.7% of cases in companies from the sample for product development, namely: most often CAD systems for product development - in 45.7% of cases, 3D technology in 18.1% of cases, and simulations in 2.9% of cases. Nevertheless, 1/3 of the companies still do not use modern technologies for product development, which creates room for improvements in their business.

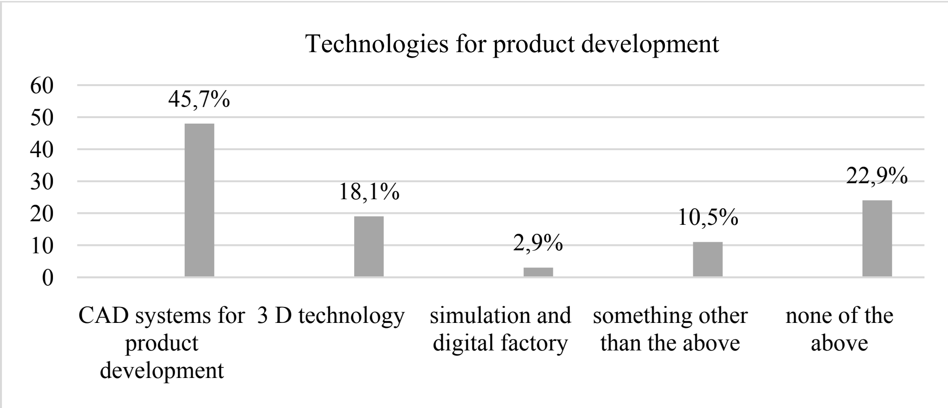

Figure 8: Overview of technologies used for product development

When it comes to the way of communication in the production and business process of the companies from the sample, as shown in Figure 9, human-to-human communication, written and oral, is used to the greatest extent (53.3% and 48.6% respectively). The Internet connection is used for communication in internal processes in 43.8% of cases, while in 55.2% of companies from the sample, human-machine and machine-machine communication is used. In most companies, combinations of the above methods of communication are used, and in only 15 cases (i.e., 14.3%) only person-to-person communication, written or oral, was reported.

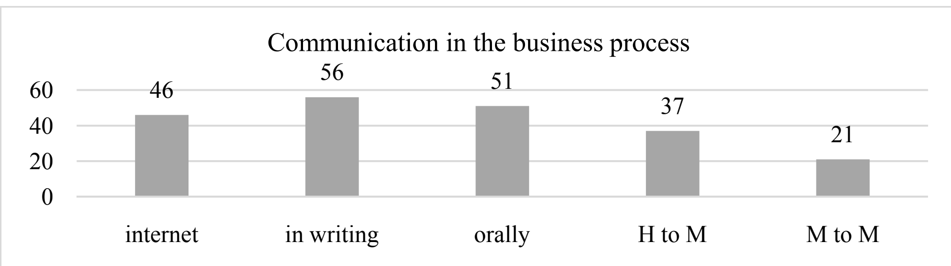

Figure 9: Overview of technologies used for communication in the company

The use of industrial robots in the companies in the sample is the least represented of all Industry 4.0 technologies. Namely, as seen in Figure 10, only 16% of the companies in the sample have industrial robots, while more than 75% of the companies in the sample do not use industrial robots to perform parts of the work and production process. 8.6% of respondents gave a neutral answer to the question about the use of robots in business and production processes (they do not know or believe that the question is not applicable to the case of a specific company). In companies that have industrial robots, in most cases these machines are well used, as can be seen from the analysis shown in Figure 11. Only one respondent reported low utilization of the industrial robots at the company's disposal.

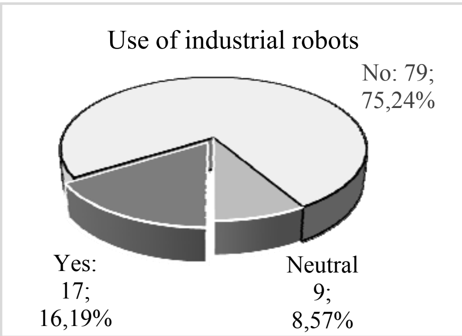

Figure 10: Use of industrial robots

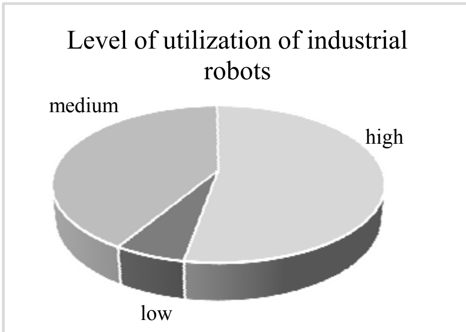

Figure 11: Utilization of industrial robots

When it comes to the use of composite materials, the situation is similar to the use of industrial robots. Namely, as seen in Figure 12, 18% of the companies in the sample use composite materials, 39% of the companies in the sample do not use composite materials in the production process, and in the case of 43% of the companies in the sample, the question is not applicable. If we take into account the structure of the sample in terms of the participation of manufacturing companies, then we can conclude that the use of composite materials is represented in approximately 2/3 of the manufacturing companies included in the research.

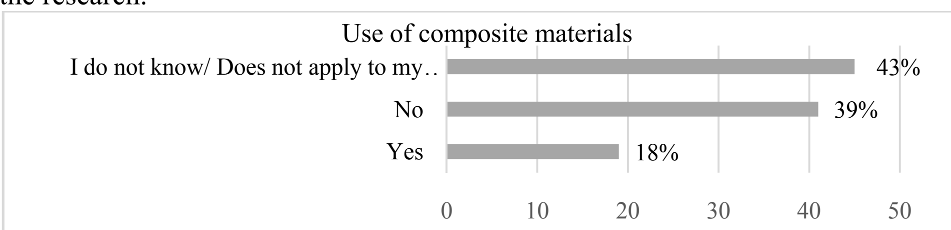

Figure 12: Use of composite materials

The use of additive manufacturing for the purpose of rapid production of prototypes and other objects is a frequent practice in modern business. The extent to which this practice is present in companies in Sarajevo Canton is shown in Figure 13. According to the respondents' answers, 20 companies, or 19% of the sample, use additive technology (3D) for prototyping and other needs. 34.3% of respondents report that this question is not applicable to their company, while 46.7% of respondents declare that they do not use 3D technology in their company.

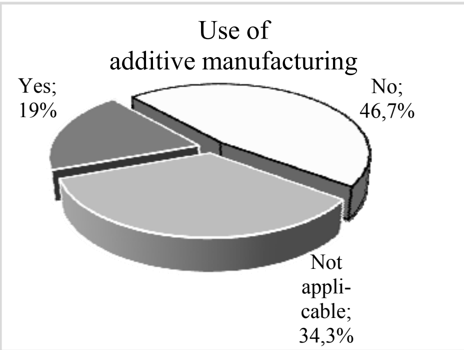

Figure 13: Use of additive manufacturing

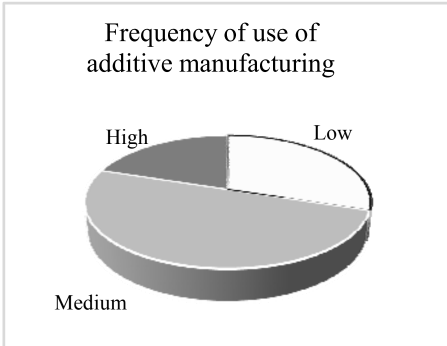

Figure 14: Frequency of use of additive manufacturing

In the companies that stated that they use additive manufacturing, this technology is mostly used moderately (in 10 companies), while in 4 companies the use of additive manufacturing for prototype development and other needs is frequent. For the sake of precision, this number makes up 20% of the total number of companies that use additive manufacturing, and 3.8% of the total number of companies in the sample. Six respondents reported infrequent use ofthis technology, that is, a low level of use, which is visible in the Figure 14.

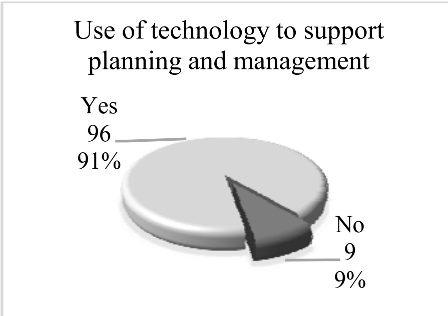

Figure 15: Use of computer technology to support planning and management

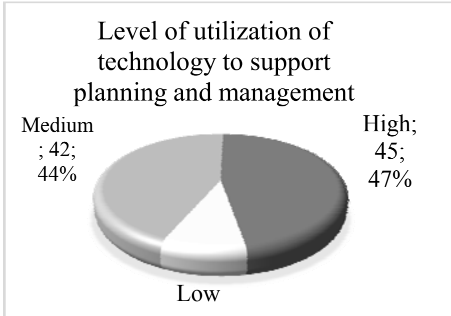

Figure 16: Utilization of computer technology to support planning and management

The last question in the questionnaire referred to the use of software for decision support, that is, support for planning and management of business and production. As expected, it turned out that this is the technology that is used to the greatest extent, i.e., in the largest number of companies from the sample. As many as 91.4% of respondents reported that their company uses software to support planning and manage materials and resources. According to the respondents' answers, 9 companies (which is 8.3% of the entire sample) do not use these programs. (Figure 15).

The use of computer programs to support planning and management of business and production in companies that rely on this technology is, as can be seen in Figure 16, high in 47%, moderate in 44%, and low in only 9% of companies that use it. It is certain that such a high frequency of application of this technology can be explained by its affordability (higher compared to other technologies) and the ratio between the costs of use and the possibilities and benefits it offers. In addition, the high level of utilization in more than 90% of the companies that have this technology speaks in favor of the fact that in the sample companies there is a willingness to adopt technologies and their mastery and use, but that the costs of acquiring certain technologies and the possibility of full use is not under favorable conditions.

4.5. Discussion

Research on the representation of knowledge about Industry 4.0 among young people and employees and the representation of Industry 4.0 technologies in companies in Sarajevo Canton was conducted on a sample of 239 respondents and 105 companies. The results of the research obtained after the conducted survey showed that among pupils and students and employees of companies in Sarajevo Canton, there is a certain level of understanding and knowledge about Industry 4.0 technologies. Slightly more than one-third of respondents arefamiliar with the term Industry 4.0, but that in most cases this knowledge was not acquired through the formal education system, i.e., that education on the topic of Industry 4.0 and basic technologies is either absent or does not provide adequate effects. The most common way in which the respondents included in the research acquired knowledge about these emerging technologies was through informal learning. Bearing in mind the described part of the research results, it is necessary to work on improving formal education programs in schools and colleges, but also to provide appropriate informal education programs on Industry 4.0 technologies in order to enable up-to-date adoption of the latest knowledge related to Industry 4.0. Despite the insufficiently high level of knowledge related to Industry 4.0 technologies among young people and employees, there is a noticeable positive perception of respondents in Sarajevo Canton about the impact of new technologies on the labor market. According to the responses of respondents, the vast majority of them expect a positive impact of new technologies on the labor market and the creation of new jobs (in more than 87% of cases), compared to ¼ of the respondents who expect a potential negative impact in terms of endangering existing jobs.

Research on the representation of Industry 4.0 technologies in Sarajevo Canton companies, based on a sample of 105 companies, showed that companies in Sarajevo Canton use I 4.0 technologies in all phases of business and production. Nevertheless, some of the technologies are used in less than 20% of cases (industrial robots, composite materials and additive technologies in 16%, 18% and 19% of cases respectively), while for other needs the application of technologies is much more frequent (e.g., for communication in 85% of cases and for planning and management support in 91% of cases).

If we compare the results obtained from this research with the data from other researches (e.g. [40, p. 53]), we can see that our respondents reported the use of Industry 4.0 technologies in business and production (covered by this research, e.g., industrial robots) in a much higher percentage 18% vs 5% in [40], or 3D technologies: 19% vs 4% in [41]). These differences may be a consequence of the specificity of the sample we used in our research, the more restrictive way of defining certain technologies in the research on which the reports described in [40 and 41] are based, or the fact that the research was conducted in Sarajevo Canton, which compared to the rest of the country has the most different resources, especially referring to knowledge resources, but also material resources.

Respecting the results of the research, it would be desirable that further research in the future to focus on the use of a wider group of Industry 4.0 technologies (compared to those that we covered in our research), as well as to pay special attention to practices in certain industrial branches, especially those of importance for competitiveness of economy of the canton and the state.

5. Conclusion

Complex processes related to the creation, development and use of Industry 4.0 technologies are taking place around the world. On the one hand, these processes imply the development of new and constant improvement of existing Industry 4.0 technologies by innovators, scientists and practitioners. On the other hand, the processes include the creation of national development strategies that should further stimulate the acceleration of the previously described processes in the function of the development of societies as a whole. In parallel with these processes, companies strive to take advantage of these changes and all the benefits available through the characteristics and possibilities of certain technologies and their combined use. These processes regularly require high levels of knowledge and available resources, which is usually unattainable for most small and underdeveloped countries. Unfortunately, Bosnia and Herzegovina also belon to this last group. In order for the Bosnian economy to be involved as effectively as possible in the processes of implementation and exploitation of Industry 4.0 technologies, it is necessary to work permanently on improving the knowledge and skills of existing and potential employees, as well as on the accelerated implementation of all Industry 4.0 technologies in the production and business processes of domestic companies, in order to increase the efficiency, effectiveness and competitiveness of the economy as a whole, but also of individual companies. Bearing in mind the limitations of the available resources that are needed to make the relevant technologies available to companies, as well as the complexity of their full use, it is desirable at the beginning of the process of implementing Industry 4.0 technologies to focus on selected groups of technologies and selected groups of companies so that the implementation process of these technologies runs as quickly as possible, and the positive effects of their use are felt as soon as possible and further distributed. These processes would require the effort of all participants: companies in terms of organizational efforts, availability of resources and cultural changes, employees in terms of learning and flexibility, institutions in terms of the development of business support programs, and the development of a national strategy for the implementation of Industry 4.0, which would give effects through increasing the competitiveness of the economy as a whole and of all companies individually.

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Disruptive Technologies of Industry 4.0: Advanced Robotics and Its Implementation in Production Processes

Isak Karabegović[1*], Edina Karabegović[2], Ermin Husak[2], Mehmed Mahmić[2]

Abstract: *The implementation of disruptive technologies of Industry 4.0 is carried out in all segments of society, but we still do not fully understand the breadth and speed of its application. We are currently witnessing major changes in all industries, so that new business methods are emerging, as well as transformation of production systems, new form of consumption, delivery and transport. All this is happening due to the implementation of disruptive technological discoveries that include: the Internet of Things (IoT), advanced robotics, smart sensors, Big Data, analytics, cloud computing, 3D printing, machine learning, virtual and augmented reality (AR), artificial intelligence, and productive maintenance. Advanced robotics is one of the most important technologies in Industry 4.0. The robotic application in the automation of production processes, with the support of information technology, leads us to ''smart automation'', i.e., ''smart factory''. The changes are so profound that, from the perspective of human history, there has never been a time of greater promise or potential danger. New generation robots have many advantages compared to the first-generation industrial robots such as: they work alongside with workers, workers perform their tasks in a safe environment, robots take up less space, robots do not need to be separated by fences, robots are easy to manipulate and cheaper to implement. The paper analyzes the trend of implementation of collaborative and service robots for logistics, which make the automation of production processes more flexible. Robotic technology is the basic technology of Industry 4.0, because without its application, the implementation of Industry 4.0 would not be possible. The trend of application of new generation robots will have an increasing character in the future, because the goals of the fourth industrial revolution cannot be achieved without collaborative robots. In other words, the objective is to achieve a ''smart production process'' or ''smart factory''.*

Keywords: *disruptive technologies, Industry 4.0, robot, flexible automation, production process, smart factory.*

1. Introduction

The implementation of disruptive technologies of Industry 4.0 in production processes enables the creation of connected company that allows production

[*1]Academy of Sciences and Arts of Bosnia and Herzegovina, 71000 Sarajevo, Bosnia and Herzegovina
[2,3,4]University of Bihać, 77000 Bihać, Bosnia and Herzegovina
E-mail: isak1910@hotmail.com

processes to discover new ways of increasing productivity and improving overall business performance.In order to ensure this, it is necessary to have a secure connection between different production systems and processes throughout the company. The new way of managing production processes aims to improve performance and better use of data that already exists by using a combination of tools that can be used to improve the system or production process [1-3]. If the disruptive technologies of Industry 4.0 are implemented in the entire company, and by integrating processes and serialdiscrete drives, efficiency and productivity will increase in all segments of the company. When we have access to production data in the production process at any moment in real time, it allows us to monitor and improve the performance of the production process itself, which enables us to implement the basic technologies of Industry 4.0. The term Industry 4.0 is already widely used, and it is related to different production concepts [4-6].The concept of Industry 4.0 is defined by many technologies (over 40 technologies). Some of these are: robotics, automation, Internet of Things (IoT), Big Data, Cloud Computing, 3D printing, smart sensors, Radio Frequency Identification (RFID), Virtual and Augmented Reality (AR), Artificial Intelligence (AI), advanced security systems, Cyber-Physical Systems (CPS), etc., as shown in Figure 1. Cyber-Physical Systems (CPS), Internet of Things (IoT), Artificial Intelligence (AI), Additive Manufacturing, Cloud Computing, and other aforementioned technologies are combined to construct dynamic, real-time optimized and self-organizing networks of values between production processes and companies. All listed components are necessary for the implementation of Industry 4.0. New generations of industrial robots have numerous advantages compared to the first-generation of industrial robots, such as: during the production processindustrial robots do not have to be separated from workers (today they work together with workers), they are light and flexible so they can be easily moved and just as easily and simply reprogrammed to perform new tasks. With these robots, automation becomes easier, more flexible, cheaper, and leads to ''smart automation''. The development of new technologies, new methods and innovations, as well as progress in industrial production resulting from these trends, presents new challenges for the robotics industry. By implementing second-generation robots or collaborative robots, we increase the reliability of the production process, reduce the production time of the finished product, and increase precision and adaptability, which exceeds human capabilities. Until now, automation has been too complex and expensive, because the installation of one industrial robot used to costabout two years' salary of one worker, and the use of a collaborative robot costs about half a year's salary. Continuous implementation of collaborative and service professional robots is necessary to have flexible automation. Robots are used to improve the quality of work, to take over dangerous, dirty and boring jobs that humans are unable to perform due to health problems or due to complexity that require flexibility, precision and reliability that humans do not have [5,6].

2. Disruptive technologies enable constructionof networking production environment

From a technological perspective, Industry 4.0 should be understood as the increased digitization and automation of production processes, that is, the networking of the production environment and the design of the digital value chain from the product to the customer. Some authors call the basic technologies of Industry 4.0 new disruptive technologies, which is inevitable because the world is in the dynamic era, and they change the production processes that are currently implemented in most companies [2, 3]. It is well-known that disruptive technologies are considered those technologies that change rooted (widespread) business processes, and even entire industries, by introducing a completely new business model based on technology. Many questions arise in the process. How to quickly profit from new disruptive technologies? How to create opportunities and at the same time maintain a good image and reputation? How to get your own organization and people on your side? Company owners are known to like controlled progress and improvements. The question is whether it is possible to achieve it in such a fast-changing disruptive reality, which becomes a burning issue for 70% of company owners.How to cooperate with other companies on innovation projects? How do we know if we can trust them? The dilemma of management consists of the fact that we are aware that we have to cooperate with others, but we must not risk losing our investments due to partners who could deceive us.

It must be noted here that innovation in disruptive technologies means the process of developing new products or services in order to replace existing technologies and achieve a competitive advantage. Namely, a disruptive product or service is aimed at a market that they could not satisfy before (new market disruption) or represents a simpler, cheaper or more economical alternative to existing products (cheaper disruption) [7].

We can see that many markets in the world have already been shaken up by new companies that offer surprising new products and services, or have innovative business models or an aggressive market strategy. Some of these well-known names are Tesla, Uber, Airbnb, SnappCarr, Nextdoor, Waze, Spotify, Picnic, HelloFresh, Zaalando, Booking.com, Virgin and Amazon. All of the above are young companies that became successful because they implemented disruptive Industry 4.0 technologies in their sector. Basic disruptive technologies in production processes are shown in Figure 1 [7].

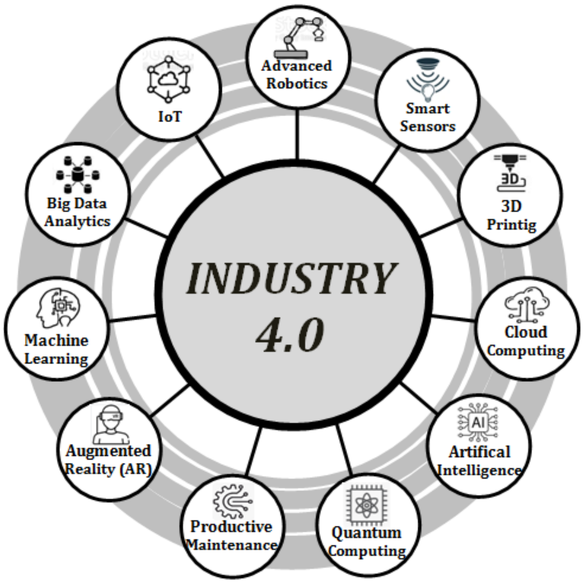


Figure 1. Basic disruptive technologies in production processes

The very concept of Industry 4.0 defines over forty technologies used by companies to meet the demands of customers, which are increasing day by day. In production processes, companies mostly use the disruptive technologies shown in Figure 1, such as: the Internet of Things (IoT), advanced robotics, smart sensors, Big Data, analytics, cloud computing, 3D printing, machine learning, Virtual and Augmented Reality (AR), Artificial Intelligence, and productive maintenance, which represent a completely new approach to modern manufacturing and business that is mostly focused on the consumer. Using the aforementioned technologies, the companies try to meet the demands of customers and close the gaps that arise in skills, but also take advantage of human expertise and investment in the implementation of the mentioned technologies in order to increase their level of productivity in production processes. The above-mentioned disruptive technologies enable secure communication within production processes, as well as simplified communication between all participants in the supply chain, regardless of where it is located. These technologies enable the monitoring of production processes and, in critical situations, making the right decision in order to ensure continuous production. We will list the basic and specific characteristics of each of the mentioned disruptive technologies of Industry 4.0 [1-3]:

- ***The Internet of Things (IoT)*** represents a system of interconnected computer devices, mechanical and digital machines, objects, animals or people with unique identifiers and the ability to transfer data via a network without human intervention or human-computer interaction. We can conclude that the desire is to connect all our devices together, that will communicate with each other and act on the basis of the information they receive from each other. In the production process, this means establishing standards based on models for connecting devices, machines and automation to a single digital platform or infrastructure, which we call the Industrial Internet of Things (IIoT). The concept of IIoT itself is similar to the concept of IoT, but it is more focused so that a network of smart sensors collects a large amount of critical production data, and forwards it to the data analysis software in the cloud. After the analysis and processing of the obtained data, information is returned about the insight into the quality and efficiency of the production operations that we monitored in the production process. With the implementation of Industry 4.0 in the company, IoT devices are deployed to monitor and control electronic, mechanical and electrical systems in production processes, in the assembly process and fully automated production processes. By implementing this disruptive technology, companies use it to manage and optimize the supply chain, gain strategic awareness of data visibility throughout the chain from procurement to delivery, and have complete control, so they can adapt to the changing market. In this way they are able to deliver services and products to the customer more efficiently, more profitable and at a higher quality rate than competitors.

- ***Big Data - analytics*** is a disruptive technology and architecture that can use the values of a large amount of different data and their processing and analysis in real time, where changes in the speed of accumulation, volume of data and types of data are included. To date, a wide range of techniques have been developed and adapted such as: A/B testing, Association rule learning, Classification, Cluster analysis, Crowdsourcing, Data fusion and data integration, Data mining, Ensemble learning, Genetic algorithms, Machine learning, Natural language processing (NLP), Neural networks, Network analysis, Optimization, Pattern recognition, Predictive modeling, Sentiment analysis, Regression, Signal processing, Spatial analysis, Supervised learning, Statistics, Time series analysis, Visualization, etc., which draw on disciplines such as statistics and computer science (especially machine learning) to be used to analyze data sets. Likewise, there is an increasing number of technologies that are used to aggregate, manipulate, manage, and analyze big data, some of which are: Business intelligence (BI), Cassandra, Non-relational database, Relational database, Semi-structured data, Stream processing, Structured data, Unstructured data, Visualization, etc. All the mentioned techniques and technologies draw on developed methods and algorithms from several fields, including statistics, computing, applied mathematics and economics.The above list of techniques and technologies is not exhaustive because more technologies that support big data techniques are increasingly being developed. By using big data analytics, companies discover valuable correlations, patterns, and trends on the basis of which they make better decisions, whereas their application enable manufacturers to experience efficiency in production, have predictive optimization maintenance, as well as automated management of production processes. By implementing this Industry 4.0 technology in production processes, the company has the ability to discover hidden variables that cause bottlenecks in production processes, and is crucial for real-time performance.Likewise, by using big data analytics, it is possible to optimize the supply chain, predict errors, product development, as well as the smart design of the company.

- ***Smart sensors*** can be defined as a device that measures a physical quantity, gives an output signal that depends on the amount of the measured quantity, converts it into a signal suitable for further processing, uses computer resources that are built into the sensor to perform a predefined and programmed function on a certain type of data which it collects, and then forwards that data over a network connection. The implementation of smart sensors, which are synonymous with Industry 4.0, monitors various production processes, collects data, makes measurements and transfers data to cloud computing platforms where the obtained information is analyzed for making decisions that are essential for improving the production process. The development and implementation of smart sensors takes place on a daily basis.The most common smart sensors used in production processes are level sensors, temperature sensors, pressure sensors, infrared sensors, proximity sensors, etc. It is expected that the development and research in sensor technology will lead to sensors that are biodegradable. This type of research requires more than 10 years.
- ***3D Printing*** is the production of elements and objects by computer-controlled robots that deposit layers of a specific material and thus form parts and objects from computer-aided design (CAD). 3D printing is used in almost all industries, especially in the automotive and aerospace industries for product redesign, and achieves lower material consumption and more complex geometry in order to increase efficiency. By implementing this Industry 4.0 technology using 3D software, which is known as generative design, it is possible to produce parts that have complex geometry, and cannot be produced by traditional production methods. Such 3D models, which are produced by generative

design software, use elements of artificial intelligence (AI). This disruptive technology of Industry 4.0 is in the research phase, and the very stability of the production of parts with this technology will begin to change, increase and enable digital transformation and product innovation. It will enable easier exchange of knowledge in the entire supply chain, as well as collaborative production in production processes.

- ***Cloud Computing*** is information technology (hardware and software) that describes the provision of IT infrastructure such as data storage space. In other words, it describes access to IT infrastructure that is available via a computer network without having to be installed on computer. The best example is companies that provide e-mail service, which store messages using cloud computing. This technology allows companies to focus on their core business, rather than spending their resources on computer infrastructure and its maintenance. This disruptive technology enables companies to simplify certain operational and management processes, centralize data storage that users can easily access, and provide real-time information exchange.Some of the advantages of this technology are reduction of costs, reduction of energy consumption, flexibility, efficiency, stability, exchange of company data independent of location, etc. Like any technology, this technology also has its disadvantages, some of which are data protectionand dependence on the IT network. The types of services in Cloud Computing are Software as a service SaaS, Platform as a Service PaaS, and Infrastructure as a service IaaS.
- ***Machine learning*** is a technology that enables computers, or computer programs, to have this ability. One of the most important abilities of human intelligence is learning, both from one's own and others' experiences, which results in the recognition of patterns based on experiences. According to Tom Mitchell's definition from 1997, machine learning implies a computer program M (Machine) that learns from experience E (Experience) for a task T (Task) where P (Performance) denotes success, if its success P in the execution of the task T increases with experience E. The implementation of machine learning in the production process improves the quality of production by detecting errors before they appear. Manufacturing companies using smart factories can perform machine learning-based automation testing to improve engineering processes and ensure fully optimized quality control. By implementing the technology, machine learning can recognize patterns and apply them to new situations in automated production processes and other areas of Industry 4.0 such as autonomous service robots in production assembly lines.

- ***Digital twin*** is a virtual copy (digital model, layout, mirror image, sample, pattern) of an imagined or real physical product, system or process in the real world (system, product, process that is simulated, i.e., real), which can serve different purposes as a digital equivalent. A digital twin is nothing more than a computer program (software) that uses data from the real world to create simulations that can predict the way a product or process will behave. These programs most often combine and integrate the Internet of Things, Artificial Intelligence and Big Data analytics to improve results. In other words, a digital twin is a digital representation of a physical object, process, service or environment that behaves and looks like its counterpart in the real world.
- ***Artificial intelligence*** is the ability of a device to imitate human activities such as reasoning, learning, planning and creativity. Artificial intelligence enables technical systems to perceive the environment, take into account what they see and solve problems to achieve a goal. The computer receives data (which has already been prepared or collected using its own smart sensors, e.g., a camera), processes it and provides answers. Artificial intelligence systems can adjust their behavior to a certain extent by analyzing previous situations and working independently. Some artificial intelligence technologies have been around for more than 50 years, but advances in computing power, the availability of vast amounts of data, and new algorithms have led to major breakthroughs in the field of artificial intelligence in the recent years. As it is predicted, artificial intelligence will bring huge changes in the future, although it is already present in our daily lives. Artificial intelligence is widely used to provide personalized recommendations, for example based on previous searches and purchases or other forms of online behavior. Artificial intelligence is extremely important in commerce, product optimization, inventory planning, logistics, etc. In addition, it is used for machine translation, search, cars, cyber security, fighting disinformation, during the Covid-10 pandemic, etc.
- ***Augmented Reality (AR)*** is one of the disruptive technologies. It works on the principle of overlaying digital objects and information on the screen of a phone, tablet or headset by recording the physical environment in real time. Augmented Reality (AR) is implemented in an industrial environment on production assembly lines. It is used to train employees in the production process for various processes of maintenance of the production process, as well as repairs on various products of industrial production. Implementation of this Industry 4.0 technology transforms the life cycle of product design. Its implementation in production processes in industry replaces traditional

paper manuals with digital instructions. It is effective when it comes to industrial training in assembly, maintenance and repair. Augmented Reality (AR) makes the verification process much faster than traditional methods. Its implementation in quality control enables production processes to verify the placement of the component in the assembly by confirming the work instructions in advance. Likewise, its implementation in logistics increases operational efficiency in the areas of storage, routing and transportation of goods. AR glasses can be worn by warehouse employees to identify the shortest path to locate and select items needed for shipment.

- ***Predictive Maintenance*** – implementation of this technology assesses the condition of industrial equipment by performing periodic or continuous (online) monitoring of the machines and devices. A series of smart sensors that send data to a centralized or decentralized network of hardware and software are implemented in the machines and devices that work in the production process. A predictive maintenance system is designed to analyze data patterns from interconnected sensor data and predict when maintenance should be scheduled. It is generally performed while the equipment is operating normally to minimize disruption to day-to-day operations. The implementation of this Industry 4.0 technology aims to prevent asset failure with far greater precision and far less downtime, and it is useful for manufacturers as it helps extend the life of equipment by early detection of mechanical irregularities in devices and machines operating in the production process. Companies that implement this technology have advantages because they get a reduction in maintenance costs, an extension of the life cycle of old equipment and a reduction in downtime to improve production. Its implementation in production processes leads to valuable data important for the improvement of production.
- ***Advanced robotics*** – the development of advanced technologies has led to collaborative robots, i.e., the second-generation industrial robots and service robots used in industry. We can also call it advanced robotics, which we define as a combination of sophisticated programming and powerful hardware that uses smart sensor technology (including ultrasonic, touch and light sensors) to interact with the real world around you. The new generation of robots is impacting manufacturing, sinceproduction processes grow in complexity and scope thanks to digitization and the application of advanced computing technologies such as artificial intelligence (AI) to multiple areas of product design, manufacturing, supply chain and retail. The implementation of second-generation robots, or advanced robotics, is increasingly being applied to help simplify initiatives, as the new, more complex operating

environment demands an ever-increasing amount of automation. The implementation of Industry 4.0 uses advanced robotics as a base technology to increase productivity, to perform and take over tasks that are done manually, to perform tasks faster and to reduce the time of product creation. In addition, the use of second-generation robots or collaborative robots offers another advantage over conventional robots in that they are easier to set up and configure on the assembly line from the start of their implementation. Advanced robots can also take advantage of simulation software to learn how to perform a series of tasks. Manufacturers are improving quality, reliability and precision on the assembly line by closing the skills gap with technology. Collaborative robots or second-generation robots are able to do this because they have the ability to adapt themselves when the procedures and the process itself change in the production process, while industrial robots did not have this ability to adapt because they had to be separated by fences so as not to injure the workers. Finally, we can conclude that advanced robotics uses smart sensors to meet the requirements of a complex production environment for automation.

By implementing the mentioned and described basic disruptive technologies of Industry 4.0 in production processes, they become digital, and the nature of production processes is transformed with the aim of creating a connected supply chain with optimized production. With the implementation of disruptive technology of Industry 4.0, companies have a unique opportunity to efficiently respond to the increasing demands of customers' needs, which are growing on a daily basis [7-9]. Companies must discover the true values of Industry 4.0 and thus improve the efficiency of the process, enable faster and simpler decision-making, as well as achieve operational growth in evaluating important criteria for the performance of a product or service. Every sector will have to face disruption and the implementation of disruptive technologies. The best example is the banking sector, where over 85 % of all payments are made online. We have countries that are the opposite example, so in China, about 85 % of online bank payments take place through non-banking companies, namely Alibaba and Samsung. In the future, an increase in the implementation of disruptive technologies is expected in all segments of society worldwide, and many disruptive innovations are expected to be implemented in health care, so that certain companies such as Apple, IBM (Watson), Philip, GEMedtronic, Johnson & Johnson, have already launched platforms for medical applications. The disruptive technologies of Industry 4.0 are the latest paradigm shift, as the term Industry 4.0 is used as a synonym for the latest major disruption in the way we use technologies (so far) in production processes [10-12]. The German government's strategy aimed to offer a strong adaptation in connection with mass production using the aforementioned technologies. However, the implementation of disruptive technologies of Industry 4.0 nowadays refers to new ways in which the offered technologies communicate with society and people. Innovations in disruptive technologies of Industry 4.0 such as: advanced robotics, Internet of Things (IoT), artificial intelligence, additive technologies, biotechnology, nanotechnology, autonomous vehicles, etc. take place according to an exponential function in relation to all other technologies, where innovations take place according to a linear function that has a slight increase[13,14]. Unlike the three previous industrial revolutions, this fourth industrial revolution differs because Industry 4.0 relies on advances in the sharing and use of large amounts of information, and it has the potential [15]:

- To connect everything and put it on the web,
- To make the business as efficient as possible,
- To help protect and regenerate the natural environment by introducing new management technologies.

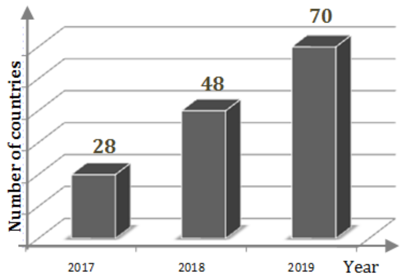
There is a trend towards increased data exchange and automation in production technologies, as well as the development of cyber-physical systems that interact with each other and humans in real time. The implementation of Industry 4.0, i.e., disruptive technologies, benefits companies, which is reflected in the optimization of complex production processes, the transformation of production processes, as well as the establishment of monitoring of production processes and other activities [16 -18]. Each company adapts to the implementation of Industry 4.0 in different ways table 1 [18]. Every technological development causechange on all levels, from the day-to-day activities of individuals to the dramatic competition between global superpowers. It is well-known that the implementation of new technologies regularly changes the course of life, communities and civilizations. Similarly, the implementation of disruptive technologies of Industry 4.0 brings changes that we expect to be positive at all levels. Nevertheless, their implementation can also bring disruptions that can have negative connotations, because its effects depend on the perspective. Let’s give one example of a positive change. The first positive example is the implementation of disruptive technologies during the COVID-19 virus pandemic. A pandemic may be a natural disruption in the sense that it is a biological phenomenon. However, the pandemic has enabled the active implementation of disruptive Industry 4.0 technologies that enabled human activities such as the search for treatments and vaccines, the development of contact tracing applications, and the widespread shift to work from homes and socializing at a distance through Internet communications, as well as global trade.

With the implementation of the mentioned disruptive technologies, the pandemic of the COVID-19 virus was stopped (they were like an antidote to the disorder), normality was established in society so that society will become even more dependent on the mentioned technologies.

Table 1. Visual improvement of a certain number of disruptive technologies of Industry 4.0[22]

Disruptive technology	A visual improvement of disruptive technology	Products, groups and resources affected by disruptive technologies	Impact of disruptive technologies on economic values
MOBILE INTERNET	Sales of tablets and phones have increased six times since the first iPhone (since 2007). In 1975, the price of the fastest computer is like the price of an iPhone 4, which has the same performance (MFLOPS).	4.3 billion people are connected via mobile internet. Almost 40% of the global workforce is in a agreement and interaction (about one billion).	70% of global employment costs. GDP related to the Internet (about $25 trillion).
THE INTERNET OF THINGS	In the last 5 years we have 300% increase in connected machines (M2M). In the last 5 years, prices have dropped by about 80-90% MEMS (micro-electronic systems) and sensors	It is assumed that 1 trillion devices will be connected to the Internet (in manufacturing, healthcare, mining, etc.). Machine-to-machine (M2M) connectivity is predicted to be around 100 million in the security, transportation, healthcare, etc. sectors.	Operating costs for manufacturing, healthcare and mining around $36 trillion.
AUTOMATION OF KNOWLEDGE WORK	We have a 100x increase in computing power from IBM's Deep Blue to Watson. In the last 5 years, over 400 million increase in the number of users of digital assistants such as Siri and Google Now.	About 9% of the global workforce are knowledge workers, over 230 million. We have around 1.1 billion smartphone users, who have the potential to use digital assistance apps.	About 27% of the global employment costs for professional workers are necessary over 9 trillion dollars.
CLOUD COMPUTING	It takes 18 months to double server performance per dollar. The monthly cost of owning a server is 3 times higher than renting a cloud.	In the cloud, there are over 2 billion global users of email services such as Hotmail, Gmail and Yahoo. Over 80% of North American tourism companies have cloud applications.	Internet-related GDP exceeds $1.7 trillion. IT spending by companies exceeds 3 trillion dollars.
3D PRINTING	The price of a home 3D printer is 90% lower than 4 years ago. Revenues from additive technologies have increased four times in the last 10 years.	About 12% of the global workforce, over 320 million are production workers. Over 8 billion toys are produced annually in the world.	Over 11 trillion dollars of global GDP. Global revenue from sold toys over 85 million dollars.
ADVANCE ROBOTICS	The price of collaborative robots is lower by about 70-80% compared to industrial robots of the first generation. In the last 10 years, robot sales have increased by about 310%	About 14% of the global workforce works with robots over 340 million. Annually, they increase by over 250 million operations performed by robots.	The cost of employing manufacturing workers is about $6 trillion. Costs for major operations are around 2-3 trillion dollars.

Another negative example of the implementation of disruptive technologies of Industry 4.0 is stated in a study by the Oxford Internet Institute (OII) from 2019, which reveals the increase in the manipulation of social media by governments and political parties around the world, as shown in Figure 2.



Data source: Oxford Internet Institute [15]

Figure 2. Block diagram of the increase in organized manipulation of social media in the period 2017-2019

A study by the Oxford Internet Institute (OII) shows evidence that the following countries: Russia, Saudi Arabia, Iran, Pakistan, Venezuela and China have engaged in information operations to influence foreign audiences through Facebook and Twitter in 2019 [15]. Many countries use the mentioned technologies to influence the domestic audience, as shown in Figure 2. In 2017, 28 countries used technologies to influence the domestic audience, in 2018 the number of countries increased to 48, and in 2019 70 countries used the aforementioned technologies to manipulate the domestic audience. This is an example of how governments and political parties use disruptive technologies in the country to control information, suppress basic human rights, discredit political opponents and suppress disagreement.

Now that we see that the implementation of disruptive technologies is causing technological disruption, and with regard to technological development and changes in business models, it is necessary to establish adaptive regulation [15,19,22]. In order to establish adaptive regulation for this purpose, a ‘’smart regulation’’ approach will help policy makers to formulate more flexible, imaginative and innovative (especially in the field of new technologies such as AI and Fintech) forms of policy instruments [23]. As there is no agreed definition of smart regulation in the world, a number of key principles for smart regulation can be identified, as shown in Figure 3.

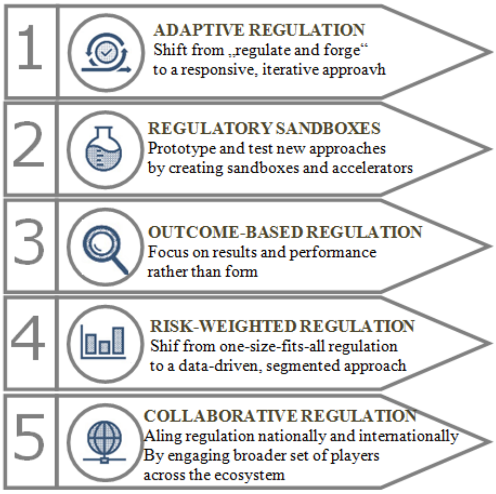


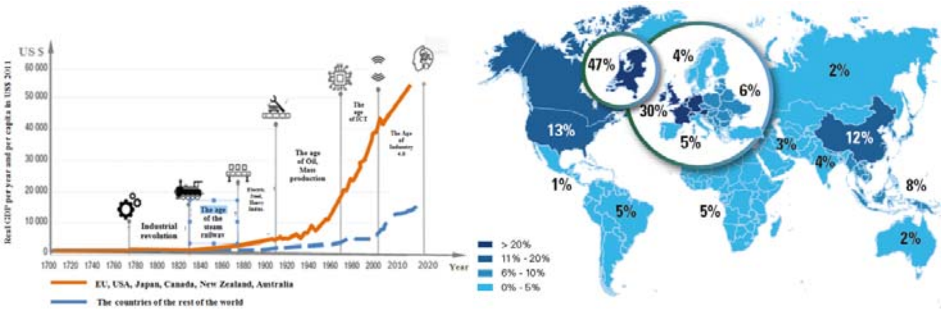
Figure 3. Block diagram of key principles of smart regulation
Data source: Deloitte [53]

The principles of smart regulation consist of five steps:

- *adaptive regulation* – where one would switch to an appropriate iterative approach,
- *regulatory sandbox (blockchain)* – prototype and testing of new approaches to sandbox creation,
- *outcome-based regulation* – focus on results and performance, not form,
- *risky regulation* – the recommendation is to abandon the regulation of one size, and go in the direction of a segmented approach based on data,
- *joint cooperation* - arrange regulations at the national and international level, by engaging broad groups throughout the ecosystem.

Smart regulation primarily refers to a response aimed at cyclical regulation, not long-term rules that set fixed legal standards for decades. Smart regulation is also about responding to problems of coordination and knowledge by being more interactive and involving multiple stakeholders, including interest groups.
The goal of the implementation of disruptive technologies of Industry 4.0 is smart production in which we have operational information in real time, reduce risk in the supply chain, reduce inventories and achieve efficient production, as well as increase of GDP, as shown in Figure 3. [7,22,23]. It is necessary to build a set of skills both inside and outside. A graphic representation of the implementation of disruptive Industry 4.0 and their impact on technological changes and inconsistencies throughout the centuries, and the increase in GDP, is shown in Figure 4.a). By analyzing Figure 4.a) we can conclude that in the last fifty years the biggest jump in the increase in living standards is thanks to investment in research, development and implementation of advanced

technologies. Many leading companies in the world are investing and implementing advanced technologies that are the key technologies of Industry 4.0. In many companies, significant progress has been recorded thanks to artificial intelligence, machine learning, the increase in available data that grows exponentially, as well as the improvement of statistical methods, i.e., advanced data analytics in digitalization and automation in production processes.



a) Increase in GDP b) Market of future expected growth

Figure 4. Impact of disruptive technologies in the world on GDP growth and the market of future expected growth of foreign markets in 2016 and beyond [7,23]

Another example is the market analysis that was conducted [23]in the Netherlands in 2016 and shown in Figure 4.b), which predicts the possibility of increasing the economy in the future. All companies see opportunities and chances to increase the economy not only in the Netherlands but also on the foreign market. Half of the companies (of those tested) predict that foreign markets will become more important in the future than the Dutch market, when considering the disruptive technologies of Industry 4.0. The estimated percentages of foreign markets for 2016 and beyond are shown in Figure 4.b), where we can see which countries and continents will have future expected growth in percentages. In order to survive and stay present on the global market, it is necessary for companies to optimize equipment, which must be reliable and safe, minimize equipment downtime, and improve problem solving. The implementation of Industry 4.0 technologies simplifies development, reduces costs and enables advanced and safer systems while meeting real-time requirements of security, energy efficiency, safety and reliability. Most importantly, it helps drive global competitiveness.

3. Advanced robotics: review of the second-generation industrial robots – collaborative robots

It is well-known that first-generation industrial robots have been implemented in all industrial branches in the world. They make about 94 % of the total number of robots used. Their implementation at that time (1960s) was welcomed for the automation of production processes in all industries. However, it was a rigid automation, since the workspace of the robot needed to be separated by a fence from the workspace of workers in the same production process, so that workers could be protected. The development of science leads to the development of advanced disruptive technologies such as: sensor technology, new materials, information communication technologies, advanced robotics and others, which led to the development of the second-generation industrial robots or collaborative robots. By implementing collaborative robots and other Industry 4.0 technologies, rigid automation of production processes is transformed into flexible automation. The second-generation industrial robots compared to the first-generation industrial robots have a large number of advantages. One of the most important advantages is that the robots do not need to be fenced off and can work alongside the workers because every second-generation industrial robot has a double protection system when it comes to workers. In order to be relevant on the global market, every company must continuously monitor the development and application of new technologies, and implement them in its production processes[20-21]. The development of digital technology is credited with the large-scale implementation of the basic technologies of Industry 4.0, which has led to a rapid flow of information so that the customer expands his requirements and seeks products that are more and more complex to manufacture. Likewise, the development of new technologies leads to market demand for different products with different designs (for example, the automotive industry). Companies must be ready for these challenges and have such production processes that they can very quickly adapt for the production of products of a different design or a different product, which is difficult to implement because it takes a long time.

Leading companies, especially in the automotive industry worldwide, are actively working on the implementation of disruptive Industry 4.0 technologies in the production processes of the industry, thus using new information and communication technologies (ICT) in order to produce more efficiently, productively and flexibly [27-29]. In order for leading companies in Germany to maintain their leading position in the production and development of technologies and standards, thy must implement new disruptive technologies so that they are the first in the export of ready-made solutions. The governments of the leading technological countries have adopted their strategies for the digitization of production processes, i.e., the strategies for the implementation of

Industry 4.0, where they want to create high quality products, to make a renaissance of production, and connect the industry to the Internet. In other words, leading companies want to modernize their production processes, and make them intelligent through the application of advanced technologies. The first step towards an intelligent production process is the implementation of industrial robots of the second generation, i.e., collaborative robots. The world is currently working on the research and development of second-generation industrial robots, i.e., collaborative robots with the aim of their continuous implementation in production processes, so that workers can safely work together with robots. This will help people in carrying out their daily tasks without any risk. Likewise, it is important to automate processes that could not be automated with the first-generation industrial robots.

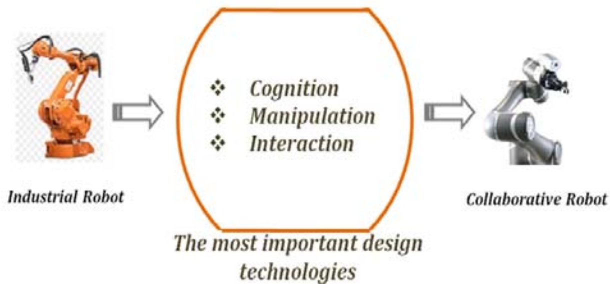


Figure 5. The second-generation industrial robots – collaborative robots are equipped with three new technical solutions compared to the first-generation industrial robots [30,31]

Companies involved in the development and production of advanced robots are facing many challenges. These challenges in the development of robotic technology, from the first-generation industrial robots to the second-generation industrial robots – collaborative robots, lie in three directions, that is, three technical areas, as shown in Figure 5.

The first challenge is knowledge that gives the robot the ability to perceive, understand, plan and move in the real world. This technical solution improves the robot's cognitive abilities so that the robot can work independently in various complex environments. The second challenge is the manipulation that gives the robot precise control and readiness. An advanced robot manipulates objects in its environment. In this way, we have a significant improvement when controlling the robot, which allows the robot to take on a greater diversity in performing tasks in different production processes. The third challenge is interaction, which represents one of the most important areas, because it gives robots the opportunity to learn and cooperate with people. Furthermore, it implies the improvement of robot-human interaction, both for verbal and non-verbal communication. The robot has the ability to observe and copy human behavior and learn from experience [31-33]. An absolute requirement for robots to work with people in an unorganized environment is safety, which is in the first place. We must note that collaborative robots are not intended to completely replace workers, but to work together with them. During the work, it is the worker that performs work in different fields, very complex operations and analytical tasks, while the second-generation – collaborative robot performs simple, monotonous repetitive operations, can handle dangerous materials, as well as lift heavy objects. Let's list some advantages that a worker has compared to an industrial robot:

- Worker has flexibility,
- Worker is ready and able to make decisions independently,
- Worker can independently solve problems, even the ones that arise in the work itself.

Industrial robots also have certain advantages compared to workers, some of which are:

- Collaborative industrial robot has endurance that is greater than that of worker,
- Collaborative industrial robot has power,
- Collaborative industrial robot has greater precision than a worker,
- Collaborative industrial robot has sensitivity.

The second-generation industrial robots – collaborative robots have the following advantages in relation to workers and the first-generation industrial robots: handling of dangerous substances (dangerous chemicals that have an impact on the health of workers, objects of high temperature, etc.), lifting loads greater than 20 kilograms, and reducing injuries at work. With the implementation of collaborative robots and service robots for logistics (such as automated guided vehicles AGV/AMR), an increasing number of production processes and logistics systems are fully automated [40]. With their improved capabilities, collaborative robots can be the key to new services and innovative production processes.

When implementing collaborative robots, safety priorities must be taken into account, because they work side by side with workers in the production process. Companies engaged in the construction and production of industrial robots are faced with a wide set of safety requirements, guidelines and standards. Here we must note that, in order to ensure reliable performance and safety, manufacturers, suppliers, integrators and operators must validate and assess the compliance of a collaborative robot according to a number of different standards, as well as take into account application-specific requirements. Companies that produce robots have found that the increase in cooperation between humans and collaborative robots expands the possibility of automation, which means an increase in the implementation of robots in all production processes. This is one of the reasons that companies develop their own solutions to meet the safety requirements of the work of collaborative robots and humans together. This paper will provide explanationof a couple of solutions developed by certain companies. The second-generation industrial robot-collaborative robot has great sensitivity because it has built-in advanced sensors such as integral force and torque sensors, as well as visual sensors that provide a safe working space and protective zones, safe collision detection, safe tool detection, safe force monitoring, etc. [26-28]. The safe protection zone can be ensured by monitoring the speed of the robot's work depending on the distance of the worker from the robot itself, as shown in Figure 6.

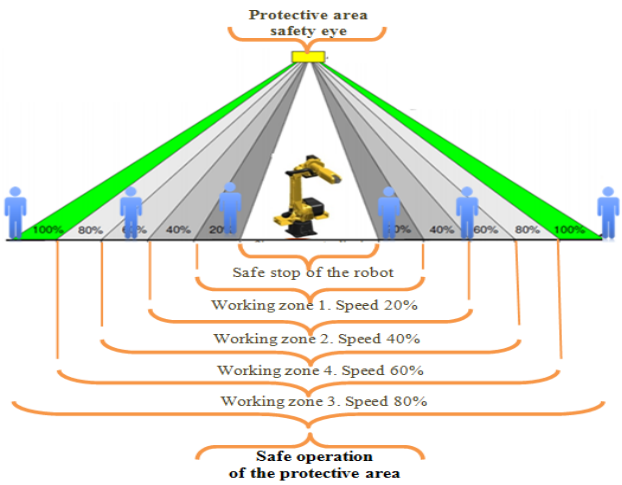


Figure 6. Ensuring the safety zone of the collaborative robot by monitoring the speed of the robotdepending on the distance from the workers [28]

The collaborative robot can easily be programmed to perform different tasks, thus giving it greater flexibility. The automatic work cycle of the collaborative robot is flexible enough to easily adapt the characteristics of the robot to the individual execution of tasks. The safety of workers during the work with collaborative robots is ensured in the work area defined by the standards ISO 10218 and ISO 13849, where functional safety must be ensured, i.e., there must be a safe protection zone. The collaborative robot is designed with sensors for direct work by interacting with workers within a common defined workspace. Such a double check safety system (DSC – dual check safety) was developed by the company ''FANUC'', as shown in Figure 7.

The DSC system is based on the laser sensor. Itmonitors additional safety, and controls the robot accordingly. When the worker is not in the specified three zones, the robot performs its work tasks at full designed speed. When the worker enters the speed reduction zone, the sensor gives information to the PLC, which gives the command to reduce the speed of operations. If the worker continues to move into the protection zone, the speed of operations continues to be reduced, and the ''Contact stop'' is activated. If the worker enters the working area, the robot switches to collaborative work mode, reduces teh working speed and ''Contact stop'' is still on.

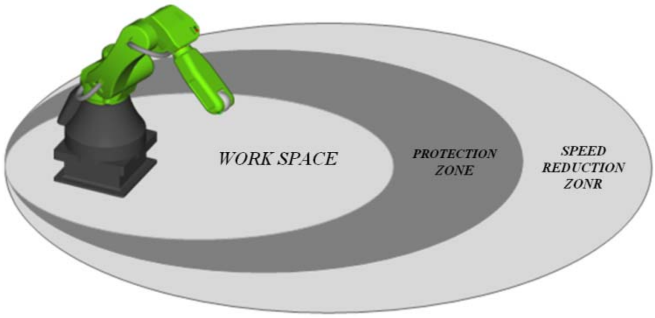


Figure 7. Securing the safety zone of the collaborative robot, DSC – Double Safety System of the company ''FANUC'' [27-29]

When the worker touches the robot, receiver or workpiece, the robot stops performing tasks (stops working). When the worker moves away, the robot continues working at a speed that depends on the zone in which the worker is located. Collaborative robots are coated with a soft coating that is sensitive so that when the contact exceeds a force of 150 N, the robot stops. Since these are sensitive sensors, the contact force can be changed in software (so that it can be lower or higher than 150N). An example of robot-worker contact is given in Figure 8.

Figure 8. FANUC collaborative robot equipped with DCS (Dual Check Safety)safety system for tracking position and speed [37-39]

The system has provided an automatic repetition of the robot's movement after the robot is stopped, at a speed depending on the space the worker is in, and in order to avoid delays. Safety is also ensured in the event that the worker's hand gets between the robot's axes, so that it does not get pinched and injures the worker. FANUC collaborative robots are equipped with ultra-safe protection to prevent contact. The protection is based on the proven disruptive technology of

Industry 4.0, i.e., smart sensor technology. Due to the protection of workers and the increased need for adequate protection of people from safety risks associated with industrial robotic systems, i.e., ensuring overall safety, an international and European standard was developed that covers safety requirements for industrial robots EN ISO 10218:2011 – ‘’Robots and robotic devices – Safety requirements for industrial robots’’, which must be met by all robots that are implemented in production processes [40].

In relation to the first-generation industrial robots (about 64 % currently implemented in production processes), the second-generation industrial robots – collaborative robots have a number of advantages, some of which are:

- The worker works safely in the robot’s workspace (robot and worker work together),
- The second-generation industrial robots – collaborative robots are characterized by simple and easy-to-handle tasks,
- By implementing the second-generation industrial robots – collaborative robots, it is possible to significantly improve performance, when operations are divided between workers and robots,
- By implementing the second-generation industrial robots – collaborative robots, we have the possibility of various levels of automation in the production process, so that we can partially automate tasks in those cases when complete automation is too complex or not economical,
- We can significantly improve non-ergonomic workstations using collaborative robots, but we must keep in mind that worker safety is an absolute prerequisite,
- The second-generation industrial robots – collaborative robots have the most significant role in Industry 4.0, which connects the real-life factory with virtual reality, thus opening future perspectives in global production,
- In order to ensure a reduction of the product life cycle and increase the variety of products, automation flexibility is required, which will result in an increase in the use of collaborative robots, prepared for use of applications that are increasingly popular with customers, which will result in an increased use of collaborative robots in small and medium-sized companies.

Companies have the following motives for the implementation of the second-generation industrial robots – collaborative robots: reduction of operating costs, reduction of capital costs, improvement of product quality and consistency, improvement of work quality for workers, respect of health and safety rules, increase of production rate, increase of flexibility in product production, saving space, etc.

3. Implementation of industrial robots with a special focus on the second-generation industrial robots – collaborative robots and service robots

In order to provide a layout of the implementation of both first-generation industrial robots and advanced robots, that is, second-generation industrial robots, it is necessary to analyze the trend of the implementation of industrial and service robots in the world for the period 2010-2021. The statistical data for the number of industrial and service robots were obtained from the from the International Federation of Robotics (IFR), the UN Economic Commission for Europe (UNECE) and the Organization for Economic Cooperation and Development (OECD) [41-43]- The data are graphically shown in the Figure 9.

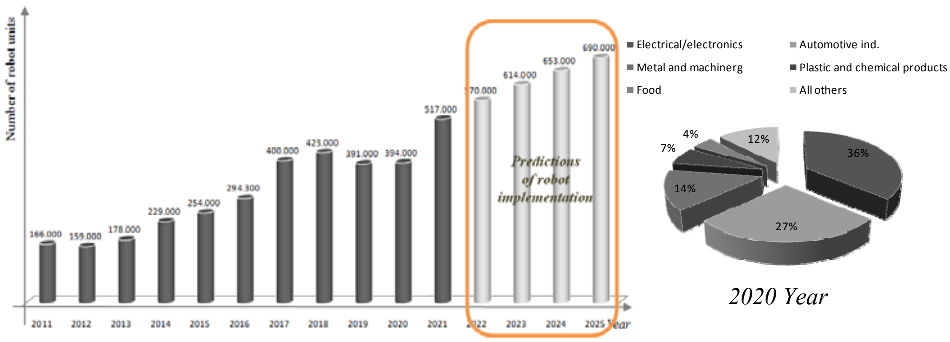


Figure 9. The trend of implementation of industrial robots in the world on an annual basis for the period 2011-2021 and the estimates till 2025

Based on the trend of the use of industrial robots in the period 2011-2021, shown in Figure 8, we can conclude that it has a growing character, from 166.000 units used in 2011 to an increase in the use of industrial robots until 2018. In 2019 and 2020, there was a decline in the use of industrial robots due to the Covid-19 virus pandemic. Slightly fewer industrial robots were used compared to the previous year: in 2019 391.000 robot units were applied, and in 2020 there were 394.000 units of robots. After the end of the pandemic, there was an increase in the trend of the implementation of industrial robots, and in 2021, 517.000 units of robots were applied. Based on the diagram shown in Figure 5, we see that in the period from 2021-2025, an increase in the implementation of industrial robots is predicted every year, with estimates of about 690.000 industrial robot units implemented by 2025. The highest implementation of industrial robots of both the first and second generation in 2020 (Figure 8) was recorded in the electrical/electronic industry with about 36 %, followed by the automotive industry with about 27%, metal industry and machines with around 14 %, plastic and chemical industry with around 7 %, and food industry with around 4 %.

Figure 10 shows the trend of the total implementation of industrial robots in the world [41-43].

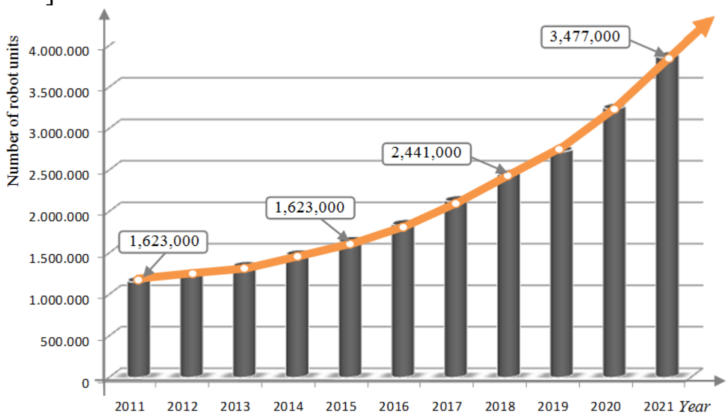


Figure 10. The trend of the total implementation of industrial robots in the world in the period 2011-2021.

The analysis of the total number of installed industrial robots in the world in the last ten years has shown that trend is increasing, and the increase demonstrates the exponential function. In 2011, there were 1.153 million units of industrial robots installed, in 2015 there was an increase to 1.623 million industrial robot units, in 2018 an increase to 2.441 million robot units,and in 2021 an increase to 3.477 million units of industrial robots implemented in the world. The conclusion is that the increase in the implementation of industrial robots in the world increased about three times in just ten years. The total amount of robot units includesthe second-generation industrial robots, also called collaborative robots. Due to their many advantages, their implementation increases on annual basis, a trend of which is shown in Figure 11 [9,41-43].

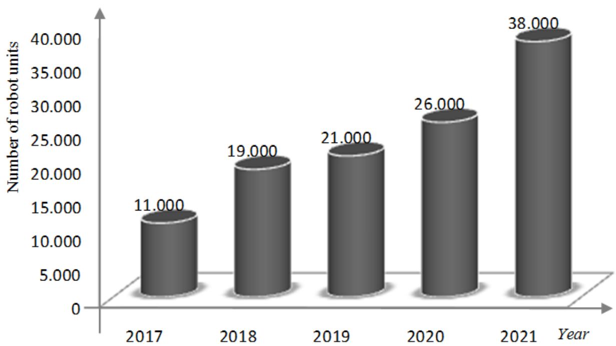


Figure 11. The trend of the implementation of the second-generation industrial robots – collaborative robots in the period 2017-2022

The second-generation industrial robots use the basic technologies of Industry 4.0. They are equipped with smart sensors and designed for direct work by interacting with workers within a common defined workspace. Based on Figure 10, we can see that their application is increasing every year, and in 2021 it reached the implementation of around 38.000 units of collaborative robots [24,26,29]. The very implementation of Industry 4.0 will enhance the implementation of collaborative robots in the coming years, since greater safety is ensured for workers. If a worker's hand stuck between the robot's axes, the worker would not be pinched and injured. Industrial robots of the second generation have a number of advantages compared to the first-generation industrial robots, some of which are:

- the second-generation industrial robots are characterized by ease of handling,
- by using the second-generation industrial robots, we are able to improve performance when performing operations between robots and workers,
- the work of the robot and the worker takes place in the joint work space, and the worker is safe from injuries,
- we are able to create various levels of automation with the second-generation industrial robots, which means that we can partially automate tasks in those cases when complete automation is too complex or not economical,
- the reduction of the product life cycle and the increase in the variety of products require the flexibility of automation, which will result in the increased use of the second-generation industrial robots,
- small and medium-sized enterprises will be able to implement the second-generation industrial robots for two reasons; the first is that the price is acceptable (very low compared to the first-generation industrial robots), and the second is that the implementation is simplified – no highly educated personnel are needed,
- non-ergonomic workstations can be significantly improved using the second-generation industrial robots, and we must keep in mind that worker safety is an absolute prerequisite,
- the second-generation industrial robots have the most significant role in Industry 4.0, which connects the real-life factory with virtual reality, thus opening up future perspectives in global production.

In order for the company to be competitive on the global market, it is inevitable that it moves towards the implementation of Industry 4.0, which will result in an increase in the use of industrial robots of the second generation [34-36]. When applying the second-generation industrial robots, companies have the following motives: reduction of operating costs, reduction of capital costs, improvement of product quality and consistency, improvement of work quality for workers, respecting health and safety rules, increase of production rate, increase of flexibility in product production, saving of space, etc. It is to be expected that the trend of using collaborative robots will be growing in the future. It is known that Industry 4.0 is being implemented in many world companies that are at the top of the global market, so that in the coming years the trend of implementing industrial robots in all industries will be continuously increasing [17,20,21-23]. In order to obtain actual information of the implementation of industrial robots in the world, we must analyze the implementation of industrial robots in the top ten countries in the world in 2020, as shown in Figure 12.

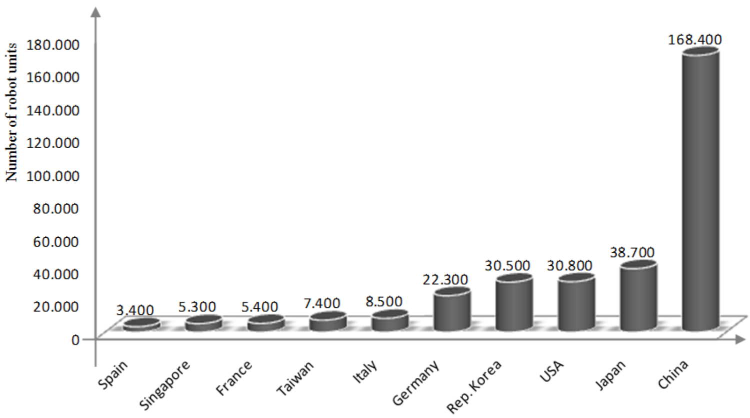


Figure 12. Trend of the implementation of industrial robots in the top ten countries in the world in 2020 [44]

The analysis of the implementation of industrial robots in the world in 2020 shows that the top ten countries are as follows (listed from lower to greater implementation of robots): Spain (3.400 robot units), Singapore (5.300 robot units), France (5.400 robot units), Taiwan (7.400 robot units), Italy (8.500 robot units), Germany (22.300 robot units), Republic of Korea (30.500 robot units), USA (30.800 robot units), Japan (38.700 robot units) and China (168.400 robot units). We can conclude that China holds the first place with a total of 42.74 % robots out of the total amount of robots implemented in 2020. Ever since 2014, China has been in the first place in terms of the implementation of industrial robots in the world, and we have already stated the reasons [34]. In order to provide a real state of the automation of production processes, the number of implemented robots in a country is not enough. We need to analyze the density coefficient of industrial robots per 10.000 employed workers in the production processes of a country's industry. An analysis of the coefficient of density of robots per 10.000 employed workers in the production processes of the industry was made for ten top countries: Spain, Singapore, France, Taiwan, Italy, Germany, Republic of Korea, USA, Japan and China, and is shown in Figure 13 [20,21,24,44]. The analysis of diagrams in Figure 13 has provided us with the conclusion that the world average of the robot density per 10.000 employed workers in the production processes of industry is 126 units of industrial robots. All ten top countries with the largest implementation of industrial robots in 2020 have a ratio of robot density per 10.000 workers higher than the world average. We have to single out China, whose robot density per 10.000 employed workers in industry was 246 units of robots, which is about 2 times higher than the world average. This is an amazing result, having in mind that only 10 years ago the robot density per 10.000 employed workers in industry in this country was negligible and far below the world average. It can be concluded that China invests a lot in robotics technology, thus demonstrating that they want to implement their strategy called ''Made in China 2025'' as soon as possible.We can see that China is the first in the world to apply for patents in robotic technology, and the first in the implementation of industrial robots [25,31,32].

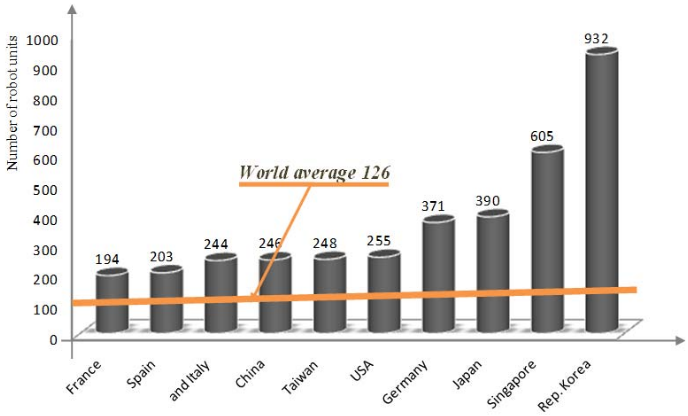


Figure 13. Density of industrial robots per 10.000 employed workers in production processes in the top ten countries in the world with the largest implementation of robots in 2020

The first five top countries in terms of the density of robots per 10.000 employed workers in industry in the world are the USA (density of 255), Germany (density of 371), Japan (density of 390), Singapore (density of 605) and the Republic of Korea (density of 932). Here we can single out two countries, Singapore and the Republic of Korea, which have the world's highest ratio of robot density per 10.000 employed workers in industry, which means that they are the countries with the highest automation of production processes in the world. We must mention that in the next few years, China will also be among the top five countries thanks to its investment in robotics technology. In addition to the implementation of industrial robots in production processes, the development of new technologies, especially robotic technology, leads to the implementation of service robots for professional use in production processes. We have conducted an analysis of the implementation of professional service robots and service robots for logistics in the period 2011-2021, which is presented in Figure 14 [25,38,44].

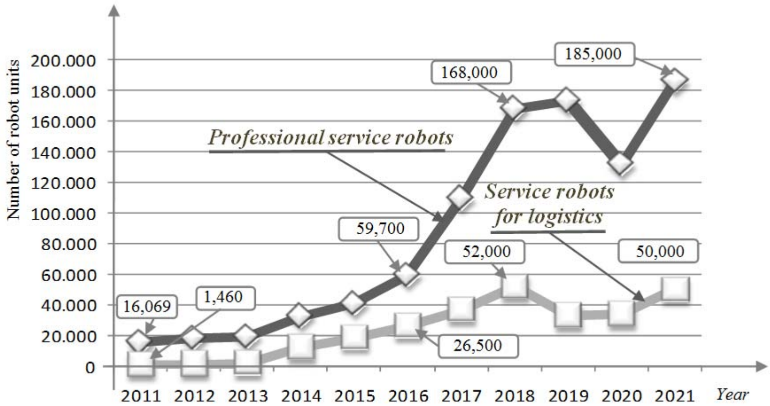


Figure 14. Diagram of the trend of implementation of professional service robots and service robots for logistics in the world in the period 2011-2021

The analysis of the diagram in Figure 14, provides a conclusion that from 2011 until 2018, the growth trend of the implementation of professional service robots takes place according to an exponential function, and from 16.067 robot units implemented in 2016, the implementation increased to 168.000 robot units in 2018. This growth trend is due to the implementation of Industry 4.0 in production processes in companies worldwide, that want to be competitive on the global market. They can achieve this only by implementing the basic technologies of Industry 4.0. One of the main technologies for automation of production processes is robotic technology, i.e., industrial and service robots. The largest number of professional service robots used in the industry is service robots for logistics, whose growth trend shows a mild exponential function in the period 2011-2018, with 52.000 robot units implemented in 2018. During the Covid-19 virus pandemic in 2019 and 2020, there was a slight decrease in the implementation of both professional and service robots for logistics. However, in 2021, following the end of the Covid-19 virus pandemic, the implementation of these robots begins to increase, so that professional service robots have reached application of about 186.000 robot units, and service robots for logistics about 50.000 robot units. It is expected that the use of these robots will increase abruptly in the coming years, and the reason for such expectations lies in the fact that companies in developed countries are implementing Industry 4.0 on a large scale, while companies in developing countries are also trying to catch up with the implementation of Industry 4.0, which means increasing the implementation of both industrial and service robots. As we have seen, many companies in the world are increasingly implementing robots, whose main aim is to remain competitive in the global market. Companies for research, development and implementation of robotic solutions offer new advanced robotic solutions every year precisely thanks to the technologies of Industry 4.0. In the recent years, artificial intelligence has been implemented in advanced robotic solutions, which is currently almost in the first place in the research technology of Industry 4.0. For the sake of illustration, we will interpret a couple of advanced robotic solutions from companies that deal with the implementation of advanced robotics.

The Japanese FANUC group provides products and services for automation by implementing robots and wireless systems for computer control. They have developed different collaborative robots that work directly with humans. Collaborative robots take on boring repetitive tasks, lifting up to 35 kg, thus maintaining the health and safety of your workers while automating entire assembly lines. They are intended to perform a number of tasks in production processes such as: AI visual inspection, quality control, arc welding, machine maintenance, palletizing, guided vision selection and placement, finishing, grinding, assembly, machine servicing, circuit suppliers, monitoring and inspection in production processes, and much more. For the sake of illustration, Figure 15 shows the implementation of FANUC collaborative robots for performing certain tasks [46,47].

Figure 15. Implementation of collaborative robots in the production processes of Fanuc Company

Collaborative robots are safe and flexible. Their implementation improves the production process, saves space, reduces costs, and they have to possibility to automate tasks that could not be automated until now. They are equipped with a wide range of sockets, so it is easier for the robot to cooperate and change to perform different tasks. It is designed to eliminate injuries and avoid collisions when working side by side with people. The possibilities of collaborative robots are endless. The American robotics company Boston Dynamics developed and implemented the agile Spot robot which is also called a half-dog or half-cyborg robot that is capable of working independently and performing a large number of tasks.Spot robot is a four-legged robot that can climb stairs and navigate difficult terrain, which gives it an advantage and allows it to be the perfect tool for surveying dangerous and inaccessible environments, as well as being able to collect data from different locations. It is designed for working and maintaining a very professional relationship, aimed at contributing to the productivity of companies, and designed for detection, inspection and remote management. The basic characteristics of the Spot robot are:

- it moves at a speed of 5.67 km/h,
- it can lift a load of 14 kilograms,
- it includes a replaceable battery, with autonomy of up to 90 minutes,
- it is resistant to rain and dust, but cannot be immersed (played) in water,
- it works at temperatures between -20º and 45º,
- it has sensors and cameras that allow a 360-degree view,
- it is foldable and can be stored, takes up less space,
- it has a possibility of adjustment and improvement by third parties.

Owing to its sensors and cameras, Spot can open doors, go up and down stairs, lift loads and even inspect difficult environments such as gas, oil and energy plants, as well as construction sites. It uses stereo cameras to avoid obstacles and people as it moves through dynamic workplaces. It is equipped to enable remote viewing. In case of a fall, Spot can even stand up independently.

The largest Australian natural gas producer Woodside has implemented an agile mobile Spot robot for inspection and autonomous detection of gas leaks through holes as part of routine maintenance, which has great advantages for plant safety in the oil and gas industry, as shown in Figure 16 [48,49].

Figure 16. Boston Dynamic agile mobile robot SPOT for industrial plant inspections

Gas processing plants are complex, potentially dangerous places, with a number of equipment that must be continuously monitored and inspected. Every company with a processing plant has its own priorities: safety, reliability and efficiency of its operations. Since safety is the main priority in the oil and gas industry, the implementation of the agile Spot robot will enable operators to maintain their facilities safely and efficiently. Figure 16 shows the agile Spot robot performing an inspection of facilities in the oil and gas industry. Robot Spot has been implemented for a range of autonomous inspection applications, including anomaly detection, thermal inspections and meter reading. In the inspection industry, Spot is equipped with an array of sensors to collect data to monitor asset condition and plant safety. These payloads include the Spot CAM+IR for visual and thermal inspections and the FLIR MUVE C360 sensor for gas detection and analysis. Spot is also equipped with an Enhanced Autonomy Payload (EAP) to improve the robot's autonomous navigation capabilities and an LTE modem for constant communication. Every 12 hours, it conducts an inspection along the same route through the plant and assesses awareness of the situation.

Figure 17. Implementation of Boston Dynamic Spot agile robot that assist in the treatment of patients suffering from the COVID-19 virus [50-51]

The Spot robot will record things that we may not notice or that we are not always there to see. Likewise, agile Spot robot is used in medical institutions to help doctors treat patients with the COVID-19 virus, as shown in Figure 17.
Doctors use it to evaluate people who think they have symptoms of the COVID-19 virus. They use a robot to measure patient's vital signs from a distance of two meters. The robot is equipped with cameras and a tablet, and uses computer vision technology. Doctors are able to measure the patient's skin temperature, breathing rate, blood oxygen saturation and pulse without being in the same room as the patient. An algorithm was developed that, using an infrared camera, enables measurement of elevated skin temperature and breathing rate, while the camera measures the temperature of the skin on the face. The algorithm then correlates this temperature with the core body temperature and determines the body temperature. Likewise, as the patient breathes in and out while wearing the mask, their breath changes the temperature of the mask, so measuring this temperature change allows researchers to calculate how fast the patient is breathing. The algorithm also takes into account the ambient temperature and the distance between the camera and the patient, so that measurements can be taken from different distances, under different weather conditions, and still be accurate. Spot Robot is equipped with three monochrome cameras that filter different wavelengths of light – 670, 810 and 880 nanometers. These

wavelengths allow researchers to measure small color changes that occur when hemoglobin in blood cells binds to oxygen and flows through blood vessels. The researchers' algorithm uses these measurements to calculate pulse rate and blood oxygen saturation. Boston Dynamics researchers have tested and measured the robot on healthy volunteers and now plan to test the approach on people showing symptoms of COVID-19 in a hospital emergency department. In the long term, the team envisions that robots could be deployed in patients' hospital rooms.
It is known that the Swiss company ANYbotics was founded in 2016 (in 2009 it already made the first prototype robot) to push the boundaries of advanced robotics, so that a new way of managing production processes can be created. The historical development of robots for automating inspection in production processes in industry is shown in Figure 18 [52].

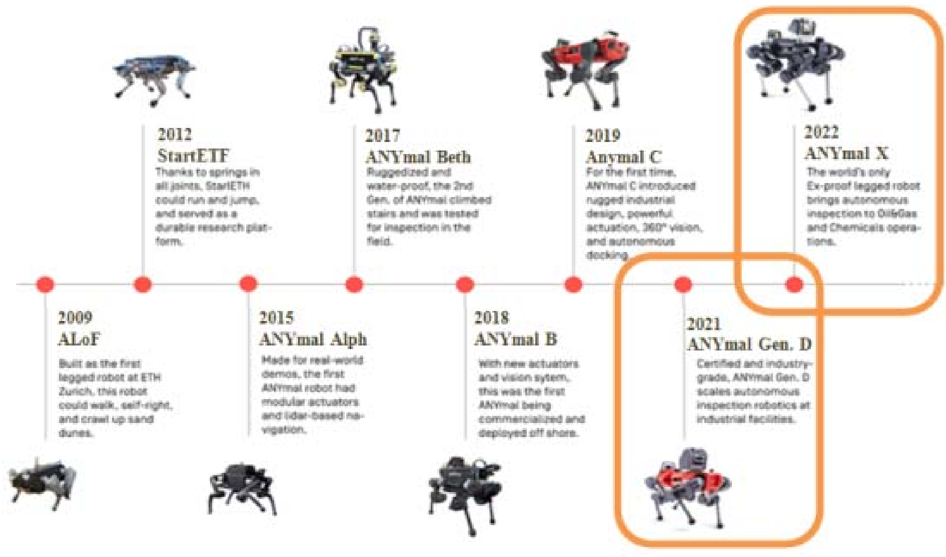


Figure 18. Historical development of the ANYmal service robot from the ANYbotics Company

Based on Figure 1P, we see that the first prototypein 2009was named AloF. The research and development of the robot has improved every year, so in the last two years they have developed a robot for monitoring and inspecting an industrial plant, namely ANYmal Gen. D in 2021 and ANYmal X in 2022. The robots are equipped with a visual camera that captures clear images and videos at long distances. In addition, it is also equipped with a thermal camera that provides precise temperature readings in the range of -20–500°C without physical interaction. Furthermore, it is equipped with a directional microphone for recording acoustic measurements in the sonic and ultrasonic frequency range, as well as an LED reflector that is used in low-light conditions to support visual inspections. It has a pan-tilt unit that uses long-range movements together with the movement of the robot base to position sensors to check hard-to-reach places.

Figure 19. Autonomous mobile robot ANYmal from the ANYbotics Company for industrial plant inspections [52]

These are built-in sensors that record the environment around the robot for smooth navigation. It is also equipped with a computer that performs computer analysis and sensor reading protocols, eliminating the need for continuous network communication. The ANYmal robot of the latest generation from the ANYbotics Company is shown in Figure 19. We must note that the legs of the ANYmal robot provide incomparable mobility when moving up and down stairs, climbing over obstacles, steps and gaps and crawling into narrow spaces. It provides reliable performance in harsh indoor and outdoor environments and through rain, water spray, wind, snow and dust, as shown in Figure 19. ANYmal's industrial plant inspection robot provides visual, thermal and acoustic insight to monitor the condition of equipment and infrastructure. Inspection algorithms based on artificial intelligence, which analyze sensory data to interpret values, classify results and detect anomalies. If necessary, we can always take control and manage the ANYmala robot manually. We can use the cameras to see in front and back of the robot, so we can navigate it. By using the ANYmal robot, we are able to automate the review and inspection of the production process from start to finish, because in this way we provide information to the operators of the production processes in order to maximize the uptime of the equipment and improve safety while reducing costs. Many companies in the world are researching and developing service robots for logistics, the implementation of which has increased to the maximum in recent years precisely because of the implementation of advanced Industry 4.0 technologies. Thus, the Danish company MiR-Mobile Industrial Robots has developed a large number of service robots MiR 100, MiR 250, MiR 250 Hook, MiR 600, MiR 1350, MiR 1350 EU Pallet Lift, which are used for logistics in production processes and warehouses, as shown in Figure 20 [53].

Figure 20. Design versions of service robots for logistics from the Danish company Mobile Industrial Robots MiR

Prior to the introduction of service robots for logistics, transportation in production processes was conducted manually. MiR service robots are collaborative and autonomous: they safely maneuver around all kinds of obstacles. If a person steps out in front of them, they will stop. Advanced technology and sophisticated software enable the robot to move independently and choose the most efficient route to the destination. When they detect an obstacle, they automatically move around it and can swerve to change their path to avoid stopping or delaying the delivery of material (Figure 21). The service robots are equipped with the latest laser scanner technology and provide a 360-degree visual display for optimal safety. The front 3D cameras have a range from 30 to 2000 mm above floor level and two sensors in each corner. These sensors ensure that the robot can see pallets and other obstacles, which it normally can barely see.

Figure 21. Examples of implementation of service robots for logistics in production processes and warehouses [53]

Service robots consume energy from the battery during operation. After the battery is discharged, it needs to be recharged. Battery charging connectors are installed in the workspace, so the service robot reaches the connector and turns on to charge the battery. When the battery is charged, the robot is ready to process the next order. The batteries have all the advantages of lithium-ion battery technology, they have a long life (about 1000 cycles) and very low self-discharge (<5%/month). The implementation of industrial robots will increase in the coming years. It is expected that the second-generation industrial robots – collaborative robots and service robots will be implemented more than the first-generation industrial robots.

4. Conclusion

Implementation of disruptive technologies of Industry 4.0 technologies such as Internet of Things (IoT), advanced robotics, smart sensors, Big Data, analytics, cloud computing, 3D printing, machine learning, Virtual and Augmented Reality (AR), Artificial Intelligence, and productive maintenance are changing production processes and organization of production and sales. The disruptive technologies of Industry 4.0 are bringing disruption to almost every industry in the world, because they have a bigger impact than we think. The impact is reflected on all segments of society as well as on small, medium and large companies. The implementation of Industry 4.0 relies on advances in the use and sharing of information and has the potential to connect almost everything on the web, which dramatically improves the efficiency of the company. By applying Industry 4.0 in the production processes of all branches of industry, the linear production process is transformed into a network production process. In other words, with all the mentioned technology, it turns into a closed-loop production process, where we have complete information about production at all times. The introduction of disruptive technologies enables companies to process and store data, and improves the design, production and delivery of their products more efficiently. Here are some of the advantages of the disruptive technologies of Industry 4.0:

- Companies will improve the business process,
- It will reduce operating costs.
- Increased productivity of companies,
- They have expanded access to the global economic market (broad customer base),
- Provides companies of all sizes with greater outsourcing opportunities (external cooperation),
- Companies will improve cooperation among themselves, as well as between departments and individuals, thanks to the availability of new communication tools;

- Advanced development, such as blockchain technology, greatly increase the security of business and personal data.

As we have seen, the disruptive technologies of Industry 4.0 such as: IoT (Internet of Things), advanced robotics, Cloud Computing, smart sensors, Radio Frequency Identification, Cyber-Physical Systems and Big Data, are crucial in the application of the concept of Industry 4.0, because they imply complete digitization of all production processes, including the process of creating a product idea, product engineering, production organization, process control and the provision of industrial services. We have also indicated how governments and political parties use disruptive technologies in the country to control information, suppress basic human rights, discredit political opponents and override dissent. Therefore, it is necessary to establish a smart regulation that refers to the answers to the problems of coordination and knowledge by being more interactive and involving more stakeholders, including interest groups. The development of advanced robotics led to second-generation industrial robots – collaborative robots.

The analysis concluded that the implementation of industrial robots of the first and second generation, as well as professional service robots, has continuously increased in the last ten years worldwide. Here we must note that advanced robotics is continuously developing, especially collaborative robots. It is estimated that their implementation will continuously increase. In the recent years, the implementation of service robots for professional use, especially service robots for logistics, has increased rapidly, as robotics companies have developed second-generation robots and fully autonomous logistics systems. Companies that implement advanced robotics in their production processes have great advantages, some of which are:

- Reduction of capital costs,
- Increased production rate and profitability,
- Increased flexibility during production,
- The possibility of automating certain operations in the production process, so that tasks can be partially automated in cases where complete automation is too complex or not profitable,
- Improving the quality of employees' work, while respecting health and safety rules,
- Continuous improvement of product quality,
- Reduction of material waste and increase in productivity,
- Transformation of rigid automation into flexible automation,
- Saving space in production areas,
- In the implementation of Industry 4.0, industrial and service robots play the most important role in connecting the real-life factory with virtual reality, which opens greater prospects for implementation in global production,

- Non-ergonomic workstations can be significantly improved with the help of robots, always keeping in mind while that worker safety is an absolute prerequisite,
- Increased product variety and reduced product life cycle require flexible automation, which will result in increased use of collaborative robots, etc.

The goal of every company present in the global market today is to achieve and receive the benefits that can be gained by implementing next-generation industrial and service robots. By using a large number of smart sensors in the production process, we always have information about production devices and machines, based on which we decide when to replace devices and machines, which enables permanent maintenance. There are three main challenges when it comes to the application of advanced robotics, both collaborative robots and service robots. The first challenge relates to methods and methodology, especially how to integrate machines and devices with an advanced robot. The second challenge is education, that is, how to prepare new generations of engineers who need to work and implement Industry 4.0. The third challenge is related to the society, primarily how to explain to people that Industry 4.0 creates new opportunities and brings a better quality of life for all of us, without being afraid of changes and everything that Industry 4.0 brings.

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3D Scanning in Industry 4.0

Adis J. Muminović*1, Jasmin Smajić2, Isad Šarić1, Nedim Pervan1

Abstract: *Modern technologies are essential parts of Industry 4.0. From automation, robotics, digitalization and additive manufacturing (3D printing) up to 3D scanning and reverse engineering. 3D scanning has a wide range of usage in today product development and design processes. This paper will present several real case studies of 3D scanning in reverse engineering andnew product development and design processes. Paper explores importance of 3D scanning technology, as integral part of Industry 4.0. Seven case studies are explored in more detail. Five of these case studies are realized in Laboratory for Product development and design at University of Sarajevo – Faculty of mechanical engineering as a part of the projects realized in cooperation with several companies from Bosnia and Herzegovina, while two of them are realized in Protodevs company in Sarajevo. Artec Eva 3D scanner and Artec Studio software were used for most of the presented case studies.*

Keywords: *Industry 4.0,3D scanning, product development, reverse engineering*

1. Introduction

Through the history of industry and manufacturing there were several periods in which important changes happens. These changes are used to divide industry in several periods. These periods are called Industry 1.0, 2.0, 3.0 and 4.0 [1]. Today, manufacturing plants are mostly in the period of Industry 4.0 which is characterized by robotization, automation, digitalization and rapid manufacturing. In addition, Industry 5.0 is already started to take shape. Main characteristic of Industry 5.0 is digitalization of whole product development and design process and manufacturing process [2]. Development and design process is one of the most important parts of every industry period. This process is changed and adopted according to the demands and needs through history. The first technology which completely changed development and design process is technology of Computer Aided Design (CAD) [3]. Through development of modern CAD software packages in the early 1990s, designers and engineers had an opportunity to make real visuals of their ideas using computer software. Today, this software is developed up to the range where classical CAD software

*1 University of Sarajevo - Faculty of Mechanical Engineering, Vilsonovosetaliste no.9, 71 000 Sarajevo, Bosnia and Herzegovina
2Protodevs Sarajevo, Vilsonovosetaliste no.9, 71 000 Sarajevo, Bosnia and Herzegovina
E-mail: adis.muminovic@mef.unsa.ba

like CATIA, SolidWorks, Inventor, etc., are divided from the software for design like 3Ds Max, Maya, etc. In addition, new modelling principles called Building Information Modelling (BIM) becomes most important parameter for integration of Industry 5.0. In comparison to CAD modelling which is focused on design, shape and materials, main focus of BIM is theinformation, which can be easily programed, automated and digitalized.
Two new technologies which currently have the biggest impact on product development and design process are additive manufacturing [4] and 3D scanning [5]. More details about how additive manufacturing influences product development and design process and Industry 4.0 in general can be found in paper [6]. The focus here is on 3D scanning and reverse engineering with special focus of presented case studies which are real industry examples realized through university cooperation with several companies from Bosnia and Herzegovina.

2. 3D Scanning in Industry 4.0.

3D scanning is not a new technology as people usually think. It exists more than 30 years but it was not used as much in industry up to the last five to ten years. Mostly due to the low quality and high price of the devices (3D scanners). Today it is used across a lot of disciplines and science fields. From digital character development for video games and movies up to mechanical engineering, archaeological science, cultural heritage preservation and digitalization. In the contest of Industry 4.0, 3D scanning is used in the fields of product development and design, industrial design, manufacturing quality control, stress and displacement analysis and movement (dynamics) analysis. There are several papers about potential of 3D scanning in industry 4.0 [7-9].

2.1. Product development and design

Product development and design is the main field where 3D scanning have the biggest influence and usage [10-12]. It is mostly used for reverse engineering processes of concept design made from clay or some other materials and for digitalization of old products which does not have technical documentation or 3D models.

In the next part of the paper several examples of product development and design case studies using 3D scanning are presented. These examples are selected examples which are realized in Bosnia and Herzegovina thought University of Sarajevo – Faculty of Mechanical Engineering cooperation with several companies from Bosnia and Herzegovina.

- **Shoe silicon protection**

This is an example where 3D scanning was used in the development of shoe silicon protection product. Goal of the product is to protect the shoes during usage. To develop protection which will ideally fit the shoes and which will not deform during waking, 3D scanning is used to make a digital representation of the shoe in its deformed shape (Figure 1). Using digital data of deformed shoe, silicon protection was designed in its deformed shape. After the application, protection will stretch and ideally fit the shape of the shoe. In addition, it will deform during walking to fit the shape of the shoe in all stages of walking. This project was realized in cooperation with the company Solvio doo from Bosnia and Herzegovina and it was realized for client from United states of America (USA).

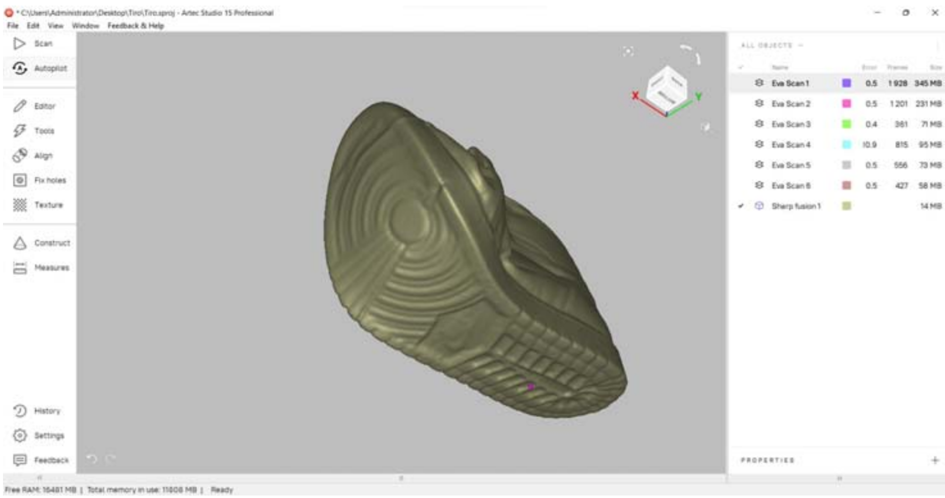

Figure 1. 3D scanned shoe

- **3D scanning in furniture industry in Bosnia and Herzegovina.**

Furniture industry is the field where 3D scanning has a lot of applications [13]. First example is the case where 3D scanning is used for digitalization of initial concept designs which is created by industrial designers, product designers or architects. First initial concepts designs are created by hand. This hand created products are than 3D scanned with the goal to create STL 3D model (point cloud) and then to create CAD (Computer Aided Design) 3D models ready for manufacturing. Figure 2 shows example of 3D scanning of a lounge chair which is created by product designer. Product designer created initial design digitally using computer software, whereas mechanical engineers used that digital design to manufacture first real example of the lounge chair. After manufacturing, designer was not satisfied with the shape and look of the chair so he used hand tools for grinding and polishing to create new modified design. The new design did not match with already created CAD models so manufacturing of more chairs was not possible. It was necessary to 3D scan the new design and to use 3D scanned models to create new CAD models ready for manufacturing.

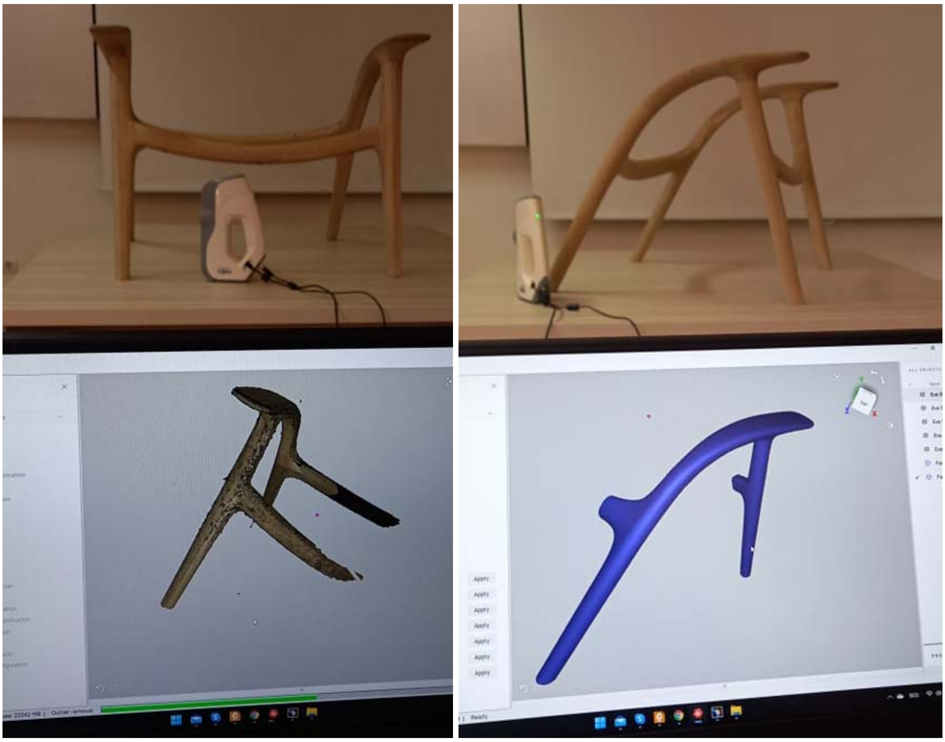

Figure 2. 3D scanning of lounge chair

Figure 3 shows final shape of the lounge chair after manufacturing. This project was done in cooperation with the company Aptha Corporation from Bosnia and Herzegovina. Designer of the chair is Stefano Bigi from Italy and chair is manufactured in Bosnia and Herzegovina.

Second example of 3D scanning in furniture industry is the case study where it was needed to create 3D CAD model of already manufactured parts of the chair. Client sent already manufactured parts, without any technical documentation and ask for massive reproduction of the same part.In this case, it is the frame of the chair which needs to be manufactured using welded pipes (Figure 4). This project was done in cooperation with Standard Furniture company from Bosnia and Herzegovina. Similar example is presented in Figure 5.

Figure 3. Final shape of lounge chair [7]

In this case it was also necessary to reproduce already manufactured part which was send by the client without any technical documentation. To be able to reproduce the same part, first step was to 3D scan initial part and to create 3D CAD models. Created CAD models were then used for tool die manufacturing using robot. After that, manufactured tool die was used to reproduce the same part massively. Whole process of reverse engineeringis presented on Figure 5. This project was realized in cooperation with the company Wood Team doo from Bosnia and Herzegovina.

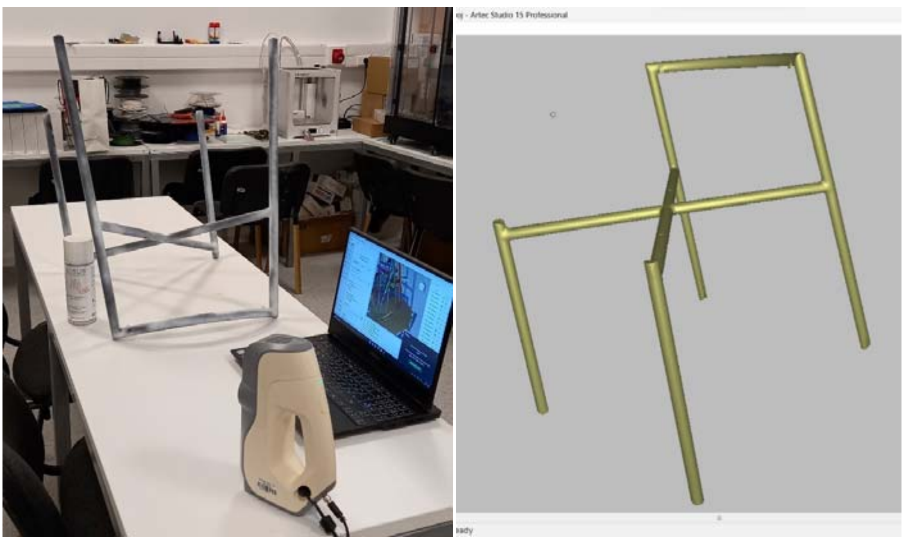

Figure 4. 3D scanning of chair frame

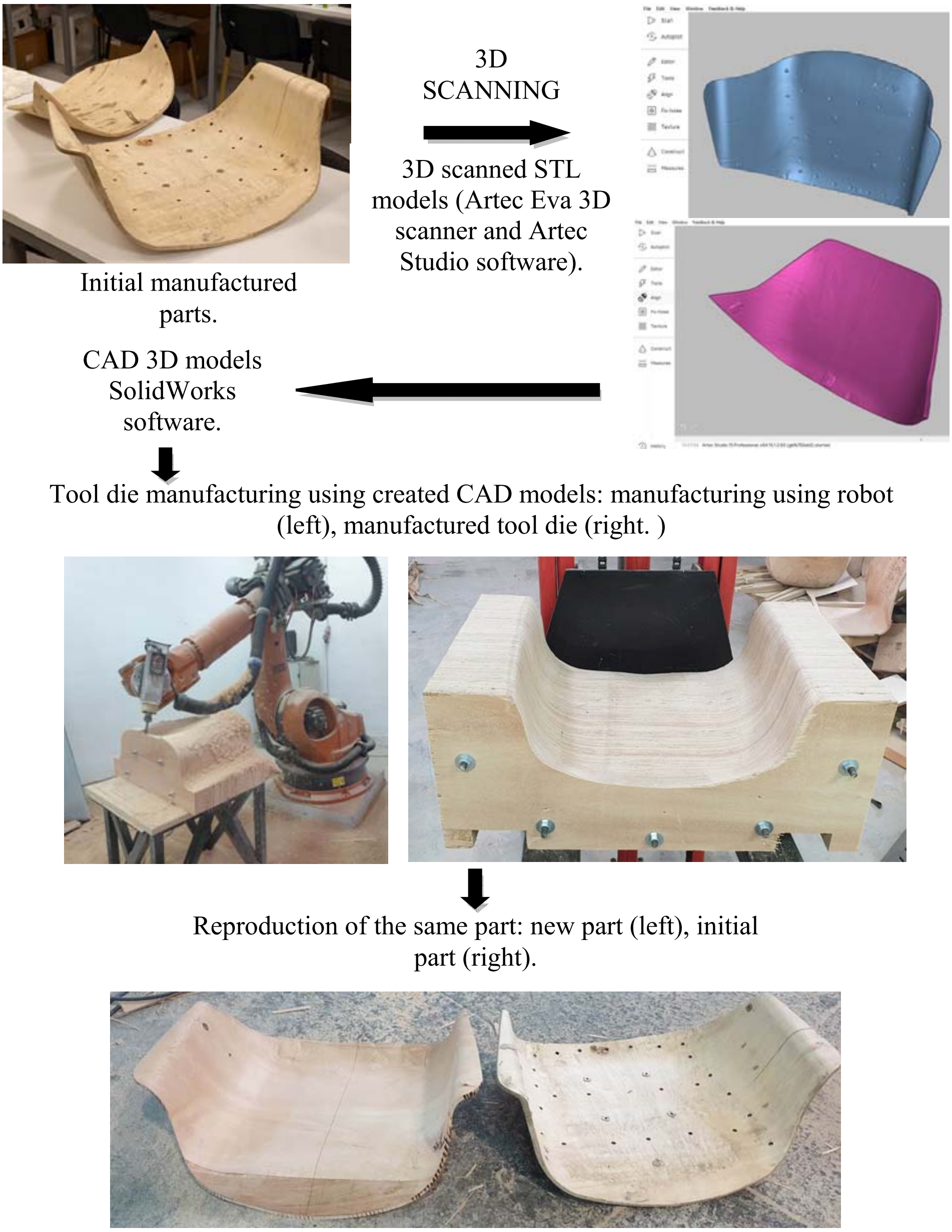

Figure 5. Process of reverse engineering of chair parts

The fourth example is the case where it was needed to develop and design a new park bench using old design from Austo-Hungarian old style (Figure 6). Old bench part was 3D scanned. Scanned data are then used to design a new bench without back support. CAD models are developed using 3D scanned data asreferences. These CAD models are adjusted for casting in sand. To create a mold for casting, these CAD models are manufactured using additive manufacturing (3D printing). This case study is a great example how additive manufacturing (3D printing) and reverse engineering (with 3D scanning) can significantly influence and modernize old manufacturing process like sand casting.

Figure 6. Park bench after 3D scanning, 3D printing and send casting

- **3D scanning in automotive industry**

Automotive industry is the field where 3D scanning is used the most, from new products development to quality control of manufactured parts. Following case study was a 3D scan of motorbike frame. It was necessary to create digital 3D model of manufactured bike frame for the purpose of next steps of the project, where it will be necessary to design other bike parts which needs to fit to the frame. Using digital 3D scanned model it is possible to create other external plastic parts and to connect it to the frame perfectly.This project was realized in cooperation with one company from Bosnia and Herzegovina. Name of the company cannot be mentioned here because of confidential agreement. 3D scanned bike frame is shown on Figure 7. This example shows that 3D scanning is especially great tool for digitalization of complex shapes and forms. Manual development of 3D CAD model of this complex shape will be time consuming and very expensive. Using 3D scanning, 3D model (STL format) is created easily and fast. This type of 3D models in STL formats can be used only as reference geometry 3D models.

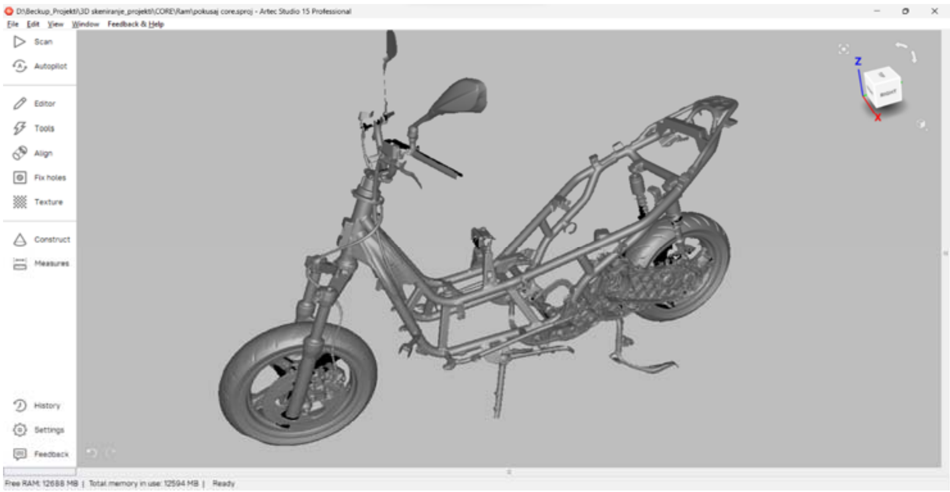

Figure 7. 3D scanned bike frame

- **3D scanning in maintenance industry**

3D scanning and reverse engineering is a great tool for maintenance industry, especially in the cases when broken parts of old machines need to be manufactured and when there isn't any technical documentation. 3D scanning can be used for digitalization of old parts. Scanned data are then used for reverse engineering with the goal to create CAD models ready for manufacturing.Figure 8 shows example of broken metal ventilator blades from old machine. Client needed a new ventilator blade but he didn't have any technical documentation of the part. In the first step, old broken ventilator is 3D scanned, and after that CAD model is developed using 3D scanned data. Developed CAD 3D model can be used for future manufacturing purposes.

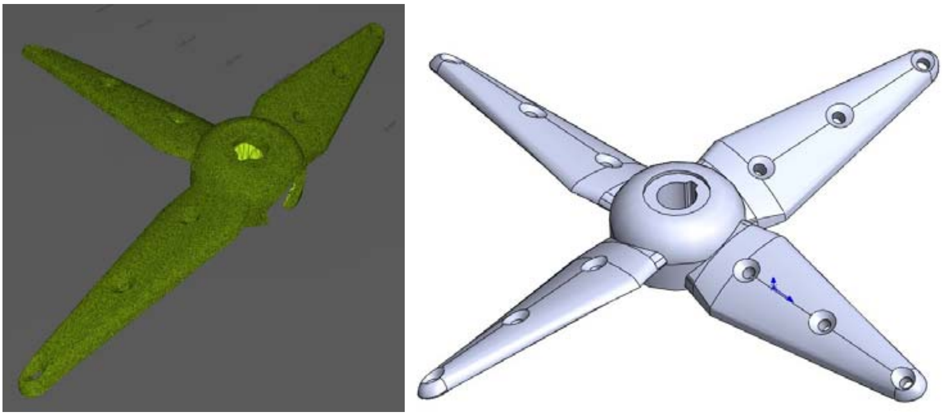

Figure 8. 3D scanned old ventilator blades (left), CAD model (right)

3. Conclusion

From above presented case studies it can be concluded that 3D scanning and reverse engineering has become integral part of today industry. It is used in almost all aspect of development, design, manufacturing and quality control. In the case of Bosnia and Herzegovina it is used a lot in furniture industry, especially for reverse engineering and new product development and design. In addition, in the case of park bench it can be seen how reverse engineering together with 3D scanning and 3D printing can bring significant improvement to old manufacturing processes like sand casting. Using 3D scanning and 3D printing, sand casting can be improved, modernized and digitalized. Manufacturing of initial first part for mold preparation is significantly cheaper and easier to make using 3D printing in comparison to the old hand manufacturing by skilled workers from wood material (in most of the cases).
In addition, from above presented case studies it is clear that knowledge about 3D scanning, reverse engineering and additive manufacturing (3D printing)has become one of the most important skills for today's engineers and designers.

ACKNOWLEDGEMENTS
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Sophisticated Transformation of Chemical, Pharmaceutical and Food Industry by Implementation of Digitalization and Automatization

Amra Bratovcic*

Abstract: *This paper will discuss the solutions and advantages of Industry 4.0 in the chemical, pharmaceutical and food industries.Industry 4.0 implies automation and process control, which enables greater process reliability and repeatability, better work control, efficient error diagnosis, maintenance support and higher product quality. In order to achieve this, it is necessary to use industrial equipment to achieve high functionality and reliability, i.e., the use of the latest developed smart technologies.it enables collection and storage of data from multiple sources in one central data warehouse in a contextualized manner, providing integrity of the underlying data and instant access from a single point.A central monitoring system provides operators with a detailed overview of equipment performance, helps maintenance personnel to eliminate errors and provides aggregation of all relevant data. The application of Industry 4.0 will improve the monitoring of process parameters, the management of production recipes, and accelerate the change of products.In addition, it enables efficient development, management and remote download of recipes to production equipment without affecting the production process on the machine/line itself.The implementation of Industry 4.0 leads to the improvement of product quality, better management of material flow, lower energy consumption, and better utilization of machines and higher productivity, which reduces operating costs and positively affects business results.*

Keywords: *artificial intelligence, internet of things, smart machines, data collection and analysis, cyber security, sensors, blockchain, robots, smart factory, machine learning, process optimization*

1. Introduction

The term Industry 4.0 refers to the 4th Industrial revolution (IR), which is based on high technologies that are rapidly developing, such as: artificial intelligence (AI) Internet of Things (IoT), smart machines that are networked and communicate with each other, robotics and advanced computers in order to significantly change the appearance of production. Industry 4.0 is characterized by integrated, autonomous and self-organized production systems. Digital transformation implies connecting all factors of production processes into a networked value chain, collecting and analyzing data for the purpose of improving the processes involved in production, optimizing costs, gaining

*University of Tuzla, Faculty of Technology, Department of Physical Chemistry and Electrochemistry, 75000 Tuzla, Bosnia and Herzegovina
E-mail: amra.bratovcic@untz.ba

acompetitive advantage, and fulfilling the expectations and wishes of customers.[1]
I 4.0 technologies leading to the automation of some production processes include: 3D printing, AI, augmented reality, robots, big data, blockchain, cloud technology, collaborative systems, cybersecurity, drones, GPS, Industrial Internet of Things, mobile technology, nanotechnology, RFID (a technology that uses wireless communication and automatically tracks and identifies specific objects), sensors and simulations.
I 4.0 creates the so-called ''SmartFactory''.In modularly organized smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions.
Investing in technology requires large financial resources. Artificial intelligence, i.e., the application of machine learning, and especially deep learning (algorithms for recognizing the state of the system and autonomous decision-making) with the aim of optimizing processes, is the core of I 4.0.Sensors and communication elements are key to automation and connect the real and virtual world in the form of a network of cyber-physical systems (autonomous robots).The basis of the development of AI refers to the use of advanced predictive tools that enable the continuous processing of large data to make decisions based on all available information at all times.Sophisticated devices based on artificial intelligence, CAD, simulations and process management are today one of the greatest values for shortening the R&D economy.
Artificial intelligence is mainly used to interact with the environment, recognize images (static or moving), human speech and environmental conditions (temperature, humidity, direction of movement, position, speed, etc.) and process the data collected in real time. The broadest application of AI is in robotics, which is mainly used in manufacturing, transportation, design, engineering, finance, information technology, diagnostics, and other processes in the home and entertainment industries.
Big data is becoming the standard for real-time decision support. Data is collected from a variety of sources, such as manufacturing equipment and systems, as well as enterprise and customer management systems. In order for big data to be used sensibly, it must be intelligently consolidated and evaluated.
Robots interact with each other and work ''in collaboration'' with humans and learn from them. The costs will be lower and the possibilities will be greater than with today's production. Robots and people are becoming more and more equal in business processes.
Simulations are mostly used to transfer the physical world into a virtual model in order to reduce costs and increase quality. They allow operators to test and optimize machine settings before physical production.
The **Internet of Things (IoT)** in I 4.0 means that computers areintegrated into devices sothattheycancommunicate with eachother.

Cyber security includes secure, reliable communications and management of identity and access to machines. According to the Report on the work of the European Investment Bank - cyberattacks threatened thousands of companies and the data of billions of people.

Connectionin ''cloud'' technology during production requires more data exchange. The result is the delivery of more data services.

Duetoitsdesign advantages, **3D printing** is increasingly being used to produce prototypes and individual components or toproduce small series of specially adapted products.It is quitet an exceptional revolution like Gutenberg's printer 570 years ago.The possibilities of 3D printing are impressive, from use for NASA technology, in the aviation industry, but also for printing human organs (using the patient's cells), as well as food printing.

Augmented reality supports a variety of services and allows access to information in real time.[2]

Central and Eastern Europe is near the end of an economic era marked by cheap labor, so foreign investment in the long term could increasingly go to countries further east and south. For example, Zoroslav Smolinsky, a trade union representative in the Slovakian VW, started working in the production facilities in 1992, when the factory was just taken over by the German Volkswagen, and he had a salary of 75 euros.Today, 12,300 VW workers in Bratislava earn an average of 1,804 euros per month.It is twenty-four times larger. According to Novotny, economists from Croatia, Europe is increasingly turning to ''industry 4.0"'', which implies intensive investments in robotization that will replace the human workforce.[3]

In Italy, there is an increase in industrial production thanks to large investments in the modernization and robotization of industrial production in the recent years. Germany also exhibits increase in the automotive and wood industry. However, Germany tried to solve the labor shortage with immigration policy. In Croatia there is a labor shortage. Due to all this, the industrial paradigm is changing.A lot is invested in research and development, high technology, and marketing.The automotive industry in the EU has adapted to the development of hybrid and electric cars.

For example, everyone who maintains that Istria was developed only because of tourism is mistaken.Istria has a strong industry.Just like the fact that Slavonia became one of the most developed regions throughout history not because of agriculture, but because of industry.According to Novotny, Croatia should turn to the industry 4.0 paradigm, and not exhaust itself by rescuing industries that are difficult to save, such as Petrokemija in Kutina, or oil refineries. There are two different examples in Požega.The Color enamel company invested in high-tech and robotic production of fireplaces and flue pipes and today has a very competitive production and is a major exporter to the demanding Western and Northern European markets.On the other hand, the company Zvečevo from

Požega, with a long tradition, did not invest in high technology and failed. Therefore, the Croatian manufacturing industry, including the food industry in Slavonia, will simply have to go in the direction of investing in high technologies that will replace the increasingly expensive labor force.[2]

2. Chemical Industry – Chemistry 4.0

Industry 4.0 combines digital and physical advanced technologies, and can potentially transform the chemical industry by improving strategic growth and streamlining operations. The chemical industry turns oil and natural gas into intermediate products, which eventually turn into the products we use every day. The global chemical industry serves as the backbone of many industries such as agriculture, the automotive industry, construction and pharmaceuticals.

Because research and development require large investments, chemical companies use big data to predict the outcome of that investment.Thatis, advanced analyzes help scientists understand the chemical properties of available materials and consider new possible combinations.

For example, BASF uses Industry 4.0 applications to implement connected systems and advanced analysis models for predictive asset management, process management and control, and virtual commissioning.In addition to these classic applications, the company has fully automated the production of liquid soaps in an intelligent pilot plant in Kaiserslautern.When a customer places an order for a personalized soap, RFID tags attached to the soap containers notify the production line equipment via wireless network connections of the composition and packaging of the requested soap, allowing the mass to be customized without human intervention. [4]

Organizations driven by business processes can use I4.0 technology exclusively to increase productivity while reducing risk, whereas those involved in development can implement I4.0 principles to generate additional income or new sources of income.

Three strategies for the modernization of chemical production are transformation of existing systems, data-driven operational framework and digitized corporate structures.

2.1. How Industry 4.0 improved production and materials management?

Industry 4.0 enables chemical companies to improve process controls, knowledge and resource management by shortening production cycles and increasing organizational productivity and efficiency. Advanced analytical capabilities help chemical companies monitor trends and encourage innovative approaches to quality control, reducing downtime as well as non-conformities. [5]

With intelligent detection methods enabled by IoT, you can achieve high-quality production in batch or continuous processing.Furthermore, Industry 4.0

technologies are being developed for better process administration, givingoperators greater freedom to monitor instrument data and plant activity.This makes it easier for the chemical industry, which is an asset-intensive sector, to continuously monitor relevant equipment such as rotors, compressors and extruders to identify and predict failures.In short, Industry 4.0 is forcing chemical manufacturers to quickly move from reactive to predictive maintenance. [6]

2.2 Processes in the chemical industry – the digital twin as a central part of process optimization

By using EPLAN, all engineering steps can be optimized and time to market can be shortened. The result of integrated and continuously enriched data (digital twin) offers added value for commercial, administrative and advanced technical processes. The EPLAN program is interdisciplinary and covers all areas including process technology, process control technology, fluid engineering and electrical engineering. Transparent and complete engineering documentation accelerates commissioning, and automatic updates of all changes ensure that the documentation follows the actual state. This in turn provides design certainty and supports changes during plant system operation.

3. Pharmaceutical Industry – Pharma 4.0

Pharma 4.0 represents the 4^{th} IR on the way to computerization of pharmaceutical production, which refers to IoT, big data, cloud computing and automation.

The initiators of the ‘’Pharma 4.0’’ concept are: AI and to the greatest extent machine learning, blockchain technology, and application of ‘’augmented and mixed reality in industry’’.

MetronikSustavid.o.o. –is an innovative supplier of automation systems and IT solutions for the digitalization of the pharmaceutical and food industry. By combining knowledge of production management processes with state-of-the-art automation and digitization technology, this company helps clients increase their competitive advantage by improving the management and control of their processes, identifying cost savings opportunities and developing optimization initiatives.[7]Solutions for automation and control of processes related to heating, cooling, ventilation and lighting can ensure appropriate ambient conditions, improved practicality, easier system maintenance and energy efficiency. [8] Process automation and control can provide greater process reliability and repeatability, better work control, efficient fault diagnosis, maintenance support and higher product quality.

Figure 1. Automation and control of heating, cooling, ventilation and lighting processes - energy efficiency

Big Data makes it possible to extract key information from your data to improve processes and reduce production costs. [9]

Figure 2. Tools for modeling and data analysis for process optimization

The Metronik company enables the safe collection and storage of data from multiple sources in one data warehouse in a contextualized manner, providing the integrity of basic data and immediate access from one point.With data integrity, we ensure that data recordings are consistent, properly organized and preserved, and that we know at all times where the reference value of a particular data record originates*[10]*.
The US Food and Drug Administration (FDA) has approved 29 AI-based technologies. Viz LVO is an application that enables rapid detection and diagnosis of stroke.It uses AI to detect and triage suspected strokes.The information reaches the doctor directly, an hour faster than conventional techniques. DreaMed is another application that is based on AI and is an automated support for deciding on the therapy of patients with type I *diabetes mellitus*.

Figure 3.Secure data collection and storage

DreaMed's algorithm is paired with a server that analyzes an individual's blood glucose concentration, insulin dose history and carbohydrate intake and enables healthinformation to the worker in order to give a personalized dose of insulin to the patients.

Machine learning as a branch of AI is used for the development and formulation of new drugs and manufacturing processes.Machine learning is used to predict the psycho-chemical characteristics of a drug, optimize the composition of formulations, optimize the production process, predict the rate of drug release, bioavailability and predict the stability of drugs.All this leads to a reduction in costs, the possibility of detecting unwanted effects in the early phase, faster results compared to existing in silico methods.Especially in the drug discovery segment, advanced machine learning techniques such as reinforcement learning, transfer learning, active learning, and deep learning are significant.

Blockchain technologies can be used in: fight against falsified medicines, and that in this sense the new concept of cryptopharmaceuticals is being mentioned more and more, in pharmaceutical supply chains, where complete control of conditions in the drug supply chain could be enabled and, improved transparency in clinical drug trials.*[11]*

3.1 Technology for the production of personalized medicines

Siemens in Vienna is developing technology for the production of personalized medicines[12]. The recently opened Viennese Living Lab, the only experimental facility in Europe, where Siemens develops various digital technologies of the future, including the one for the production of personalized medicines. Technology for the production of personalized medicines in small batches that are adapted to each individual and the health needs of his organism based on data on genetic material and other biomarker information.

Figure 4.Living Lab in Vienna

3.2 What can pharmacy expect from Industry 4.0?

I 4.0 is focused on digitization using cloud systems. In a smart factory, a networked process provides transparency across teams and processes, including sales forecasting, raw material ordering, machine maintenance, floor plan operations, reporting and delivery. The raw material ordering team has access to AI sales forecasts and adjusts the order accordingly. Operators, in the same way, approach sales forecasts and adjust the speed of the production line. If operators have information about a smaller order quantity, they can use that time for machine maintenance. To create smart production, it is very important to determine which area in the production process should be digitized first, because pharmaceutical companies have different digital maturity and needs.

3.3 Increased patient safety

Patient safety has always held a particularly important place in the pharmaceutical industry, and any technology that can advance this requirement is very important.In order to ensure the high quality of medicines, they must be stored and transported under certain conditions.Any change in physical conditions (temperature, humidity, presence/absence of light or air) can affect the quality of both raw materials and final products. IoT sensors - a solution for Industry 4.0 - are designed to monitor small variations in the environment and have become a key player in patient safety.[13]

3.4Cybernetic-physical system (CPS) for pharmaceutical production in industry 4.0
The key elements of CPS are public cloud, private cloud and manufacturing facility. Public Cloud are application services for external users. Private cloud includesspecific information for remote monitoring systems, manufacturing, energy management, laboratory information, management, and modeling

andsimulation. Public and private clouds digitally reflect the state of the physical system, enabling real-time optimization and prediction.
The production platform includes hardware, PAT tools and real-time release tests (RTRt).PAT ensures the control of the production process and RTRt ensures the quality of the product based on the data collected during the production process. Processing operations (e.g., delivery, wet granulation, fluid bed drying, grinding, mixing, compression and tablet coating) are connected to the local network and the cloud via the Internet.
Production process data is recorded and stored using two key technologies: data storage technology (cloud) and data collection technology (advanced sensors).This data-rich environment enables the development of big data and simulations, AI and adaptive control, digital twins and cyber-physical (IoT) systems. These combined technologies enable intelligent, precise, real-time collaborative robotics and augmented or virtual reality technologies to control and manage production. The entire smart factory is supported by a wireless internet network and sufficient cyber security.

4. Food Industry

Throughout the food industry, it is essential that production is thoroughly documented so that products and their ingredients can be traced.[14] Fulfillment of this requirement significantly depends on the perfect operation of IT. The Manner company is currently investing around 40 million euros in the production site. A new data center was also built.Rittal supplied the IT infrastructure.
Technology is a support for decision-making. The collection of huge amounts of data, storage and analysis (IT) enables a much better insight into the various processes on the basis of which better decisions are made in the food industry[15]. The packaging changes in parallel with the threats. Digitized processes in the supply chain are more exposed to new security threats.

4.1 New tracking technologies

With the help of track-and-trace package tracking technology, Radio frequency identification (RFID), QR codes and (IoT) it is possible to detect any anomalies and track any lost or stolen item within seconds.[16]
Smart technology embedded in packaging or products makes it possible to sendinformation in real time, prevent counterfeiting,and goods authentication (embedded microchips).
RFID tags and QR codes are commonly used today for improving the level of identification and traceability throughout the supply chain. They enable companies to strengthen quality control systems and react more quickly to potential problems. RFID tags play an important role in new approaches to

packaging protection. It is based on a printed antenna with a microscopic chip that transmits a radio frequency signal. It can be used to track products during transport, monitor inventory and increase security.
RFID tags can be used for: sending information to the customer's mobile phone to inform them about the delivery date, to track the location of the package in the warehouse as well as the time of loading it into the delivery truck,to track the delivery from start to finish, while reducing the risk of theft during transport,and to detect unauthorized access (signal interruption). The total value of the RFID tag market in 2022 was about 13 billion dollars.
NFC and Bluetooth Low-Energy (BLW) technologies are so simple that consumers can use them on their mobile phones, (quick access to package information and delivery tracking). Each NFC chip (security tool) has a unique serial number assigned by the manufacturer, (customers can be sure of the authenticity of product information). It is easier for companies to track items in case of theft.[17]

4.2 Product traceability

Characteristics of the traceability system: Product identification – dimensions, volume, weight, area, packaging, cost, life cycle length;Tracking data – tag/number, type, level of detail, dynamic, data storage requirements, data confidentiality; Product routing (production process) – production cycle, activities, delivery time, equipment, manual operations, automatic operations, storage systems.

4.3 Product identification and marking

Identification is done using the technology of direct or indirect labeling of product parts - DPM (Direct Part Marketing).

Figure 5. Two-dimensional codes

Direct and indirect technologies are techniques for labeling parts and raw materials. Indirect labeling includes paper labels, plastic, metal, RFID tags, tags, etc. [18-19]Direct marking includes Dot Peen technology, laser marking, electrolytic-chemical treatments, engraving, InkJet technologies, embossing, etc. Indirect marking refers to marking that requires an identification holder, and for this application, labels or labels with a numerical, alphanumeric, barcode or 2D code are most often used.This method is only used to mark larger parts or products.RFID tags are used to identify parts with advanced IoT systems that enable mutual interaction and communication between cutting resources in real time.Ultra-small RFID chips have been developed, e.g., the Hitachi micro-chip, size 0.3x0.3 mm. Direct marking of parts includes marking of the surface, and is most often a form of marking of small parts and components.These marks can be alphanumeric or numeric characters, barcodes or 2D codes.Laser marking is the most common technology used for direct marking of parts.miDoT is a new method being developed for the unique identification of small parts using glittering ink in a radius of less than 1 mm.This ink is applied with a pen, and the pattern is read and matched against a database.The advantage of this method is the low cost of materials compared to the high cost of data storage and processing.

Cardboard packaging is one of the most widely used material for transporting products in the world, with more than 100 billion boxes produced in the US alone.To ensure that packages reach their destination, many companies mark cardboard packaging with 1D or 2D barcodes. Markings are applied directly to the side surface of the packaging, and this procedure is called direct marking of transport packaging.[20]

Figure 6.Marking of cardboard packaging

5. Conclusion

Fourth IR combines advanced production technologies to enable integrated, autonomous and self-organizing production systems that operate independently of human involvement. Industry 4.0 refers to the collection of data from the production process, the digitization and analysis of data (Big Data) leading to information, which, according to the meaning of AI, creates knowledge and leads to wisdom that is achieved through the combined insights of digital maturity. Digitization, standardization and automation are all trends that industrial sector cannot avoid. Integrated design of control systems and a strong engineering program can make a significant contribution to the improvement of automation in the company.

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Digital Twin: Background, Challenges, Enabling Technologies, Benefits, and Use Case in the Elevator Industry

Edisa Dreković[*1], Isak Karabegović[2], Nikola Stojić[3]

Abstract: *Digital twins represent a new paradigm that brings fundamental changes to business and asset management. The proliferation of connected devices and sensors has generated vast amounts of data from physical assets and processes. Digital twins leverage this data to create a virtual counterpart that reflects the behavior, performance, and characteristics of their physical counterparts in real-time. The definition of digital twins encompasses a wide range of applications and contexts. This paper provides an overview of existing literature on digital twins, including their definition, key characteristics, and classification. Additionally, it highlights potential challenges and limitations associated with digital twins and identifies the technologies that enable their implementation. By understanding the fundamental concepts and technological advancements in the field of digital twins, organizations can harness their potential to enhance their business, optimize resources, and foster innovation. Numerous examples of digital twin applications in various industries are highlighted in this paper, with a particular focus on the elevator industry.*
Therefore, this paper serves as a comprehensive source of information for researchers, practitioners, and decision-makers who wish to explore the application of digital twins in different industries and domains.

Keywords: *Digital twin, benefits, challenges, enabling technologies, use cases*

1. Introduction

Digital twins have proven to be valuable in a wide range of domains, including manufacturing, healthcare, infrastructure, and smart cities. By creating virtual replicas, businesses can benefit from real-time insights, operational optimization, reduced downtime, and substantial cost savings.
Adopting digital twins provides organizations with business growth, enables them to effectively respond to evolving market dynamics and maintain industry leadership. Digital twins serve as enablers of data-driven decision-making by providing a platform to simulate various scenarios in a virtual environment,

[*] PhD candidate, University of Niš, Faculty of Economics, Trg kralja Aleksandra Ujedinitelja 11, 18000 Niš, Serbia,
[*] Academy of Sciences and Arts of Bosnia and Herzegovina, Bistrik 7, 71000 Sarajevo, B&H
[*] Schindler Management Ltd., Zugerstrasse 13, 6030 Ebikon, Switzerland
E-mail: edisanp@gmail.com

which provides businesses with extraordinary opportunities to test and fine-tune strategies before implementing them in the physical domain. Consequently, digital twins facilitate informed decision-making, mitigate risks and encourage exploration of innovative approaches, leading to improved results and competitive advantage.

In addition to their manifold advantages, digital twins are not without the challenges. These challenges encompass various aspects, including the acquisition and integration of data from disparate sources, concerns surrounding data security and privacy, computational demands, and the necessity for precise modeling and simulation. Furthermore, the successful deployment of digital twins necessitates careful consideration of factors such as interoperability, scalability, and the potential disruption of existing workflows.

A comprehensive understanding of the characteristics and classifications of digital twins is pivotal for their effective implementation. Equally important are the enabling technologies that play a crucial role in the development and utilization of digital twins. Data acquisition technologies, including sensors and Internet of Things devices, form the fundamental infrastructure for capturing real-time data. Advanced analytics techniques, machine learning algorithms, and simulation tools facilitate data processing, analysis, and the creation of virtual representations.Visualization technologies, such as virtual reality and augmented reality, contribute to an enriched user experience and enable seamless interaction with digital twins. These technologies provide immersive and interactive interfaces that enhance the understanding and utilization of digital twins. Their application spans across diverse domains, including manufacturing optimization, healthcare advancements, and infrastructure performance enhancement, showcasing the versatile potential of digital twins.

Regarding the future of digital twins, research conducted by Allied Market Research and Markets and Markets indicates significant growth in the digital twin market in the coming years. The global digital twin industry was valued at $6.5 billion in 2021 and is projected to reach $125.7 billion by 2030 [1]. Markets and Markets also forecast a market opportunity for digital twins to increase from $6.9 billion in 2022 to $73.5 billion by 2027 [2]. According to Allied Market Research, system digital twinsare expected to have a dominant share in the market during the forecast period. This is attributed to their widespread adoption, particularly in industries such as automotive, electrical, gas, and energy. Product digital twins rank second in terms of market share, followed by process digital twins. The report highlights that the automotive and transportation industries held the largest market share for digital twins in 2021, followed by aerospace, retail, energy, and oil & gas sectors.

The digital twin serves as a fundamental component in the construction of the metaverse. These virtual representations intricately mimic real-world objects, and the next evolution of digital twins will feature photorealistic graphics,

physics-based simulations, artificial intelligence integration, and interconnectedness within metaverse ecosystems [3].
The accuracy and reliability of digital twins are supreme. The high degree of reliability ensures that digital twins closely replicate the behavior and characteristics of their real-world counterparts, enabling robust predictive capabilities. Organizations are tasked with capturing comprehensive data related to a physical object and then seamlessly integrating the real-time information into their digital twin systems. In this way, the digital twin remains in sync with its physical counterpart, improving its capabilities and overall efficiency.

2. Background, Definition, Characteristics and Classification

The inception of the Digital Twin concept can be traced back to the collaborative endeavors of Michael Grieves from the University of Michigan and John Vickers of NASA. In 2002 Grieves first introduced the ''Conceptual Ideal for PLM'' which encapsulated all the essential elements that define the Digital Twin: the real space, the virtual space, the critical link enabling the seamless flow of data from the real space to the virtual space, the reciprocal exchange of information from the virtual space to the real space, and the existence of virtual sub-spaces. In later works, Grieves [4] used a model named the Mirror Space model.

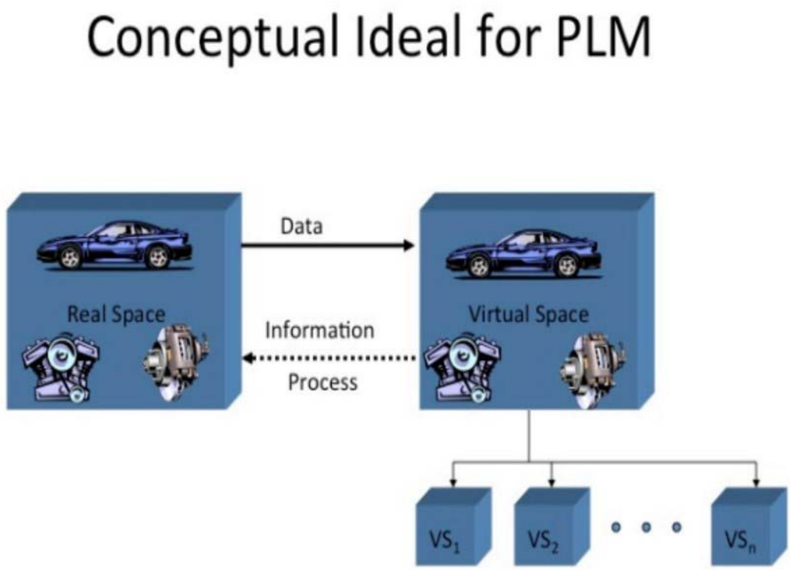

Figure 1. Conceptual ideal for PLM by M. Grieves

The aerospace industry, especially NASA, played a vital role in the development of digital twins. NASA pioneered the use of virtual models and simulations to replicate and monitor the behavior of spacecraft and satellites, referred to as ‘’mirror models’’. During the Apollo 13 mission, NASA utilized simulators and integrated digital components into a physical model of the spacecraft following an oxygen tank explosion. As Stephen Ferguson [5] explained, this incident illustrates key characteristics of digital twins, such as the physical model, adaptability, connectivity, and responsiveness. Digital twins are effective when dealing with physical assets that are temporarily inaccessible for direct human intervention, as was the case with Apollo 13. Furthermore, constant feedback from the physical asset is crucial for updating the digital twin’s condition and informing engineering decisions, a requirement NASA achieved through advanced telecommunications. Nowadays, the Internet of Things is commonly used for the purpose of connectivity. Additionally, digital twins should be adaptable to changes in the physical asset, and NASA demonstrated this through rapid reconfiguration of simulations to provide critical information during the mission. Moreover, NASA utilized multiple interconnected models, indicating that modern digital twins are not solely based on a comprehensive single model but can combine different models to account for various aspects of performance. Lastly, the swift response of the digital twin to the events of Apollo 13 showcases its ability for rapid implementation and adaptation after critical damage to physical assets.These digital representations significantly enhanced mission planning, performance analysis, and diagnostics.

The term ‘’Digital Twin’’ was first mentioned in NASA’s draft version of the technological roadmap [6]. Interestingly, although the term emerged in the 2010 roadmap, NASA had previously implemented a similar concept during the Apollo program, constructing two identical space vehicles to mirror each other. A clearer overview of the evolution of digital twins is provided in Figure 2.

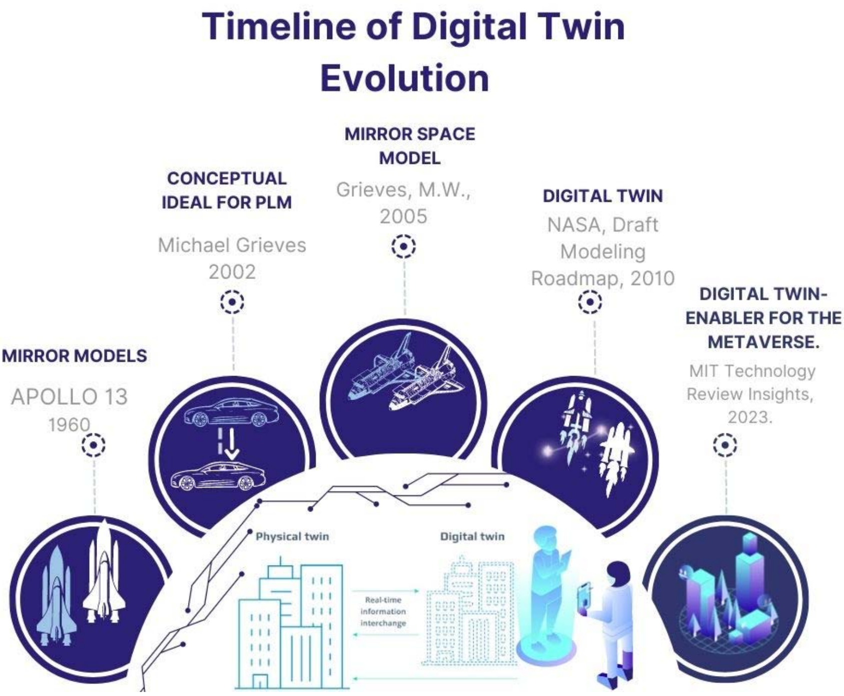

Figure 2. Timeline of digital twin evolution

Today, different authors describe the digital twin in various terms. Therefore, definitions are referring to the digital twin as a simulation, technological framework, description of a component, virtual representation, informational construct, digital footprint, links, virtual and digital model, digital mirror, replica, and digital representation of its physical counterparts. These various terms and descriptions in the literature reflect the diverse perspectives and applications of digital twin, emphasizing its role as a digital representation, counterpart, or simulation of the physical entity.

Table 1. Digital twin definitions

DIGITAL TWIN DEFINITIONS		
Authors, Year	**Definition**	**Terms**
Glaessgen, E.; Stargel, D. (2012)	''The Digital Twin integrates ultra-high fidelity simulation with the vehicle s on-board integrated vehicle health management system, maintenance history and all available historical and fleet data to mirror the life of its flying twin and enable unprecedented levels of safety and reliability''.[41,1818 p.]	Simulation
Shafto, M. et.al. (2010)	''A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin''. [6., 7. p.]	
Tao, F., Cheng, J., Qi, Q. et al. (2018)	''Digital twin is an integrated multi-physics, multiscale, and probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin''. [42, 3564 p.]	
Gabor T., et.al. (2016)	''These ultra-high fidelity simulations are commonly called a digital twin with respect to the system they model''.[44, 374, p.]	
Zhuang, C., et.al. (2018)	''The proposed digital twin model enhances the ability to digitally simulate how the production line will perform in the real world''. [43]	
Trancossi M., et.al. (2018)	''Digital Twin is the technological framework that allows an effective lifecycle analysis of a system and an effective comparison of different configurations. It allows determining the digital model of a physical system and replicating its evolution''. [45,303, p.]	Technological framework

Boschert, S. and Rosen, R. (2016).	''The Digital Twin itself refers to a comprehensive physical and functional description of a component, product or system, which includes more or less all information which could be useful in all—the current and subsequent—lifecycle phases''.[46,59, p.]	Description of a component,
Rasheed, A., et.al. (2020).	''A digital twin is defined as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling, and improved decision making''.[47, 21998, p.]	Virtual representatio n
Kritzinger, W., et.al. (2018)	''The Digital Twin in its original form is described as a digital informational construct about a physical system, created as an entity on its own and linked with the physical system in question''. [14, 1016, p.]	Informational construct
Grieves, M. & Vickers, J., (2017)	''Digital Twin (DT)—the Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level''. [4, 94, p.]	
Mayani, M.G., et.al. (2018)	''Digital Twin refers to digital footprint of physical systems in the various assets which act like a bridge between physical and digital world''. [48, 1, p.]	Digital footprint
Dietz, M., & Pernul, G. (2019)	''The Digital Twin (DT) is an asset's virtual counterpart that enables enterprises to digitally mirror and manage an asset along its lifecycle''. [49, 1, p.]	Counterpart
Negri, E., et.al. (2017)	''The Digital Twin (DT) is meant as the virtual and computerized counterpart of a physical system that can be used to simulate it for various purposes, exploiting a real-time synchronization of the sensed data coming from the field''. [50, 940, p.]	

Canedo, A. (2016)	‘’Digital Twins are a new mechanism to manage IoT devices and IoT systems-of-systems throughout their lifecycle’. [51, 1,p.]	Links
Barricelli, B., et.al. (2019)	‘’The DT is a virtual model of the physical object with the potential of understanding changes in the status of the physical entity through sensing data, to analyze, predict, estimate and optimize changes’’. [52, 1, p.]	Virtual model
Singh, M., et.al. (2021)	‘’A Digital Twin is a dynamic and self-evolving digital/virtual model or simulation of a real-life subject or object (part, machine, process, human, etc.) representing the exact state of its physical twin at any given point of time via exchanging the real-time data as well as keeping the historical data. It is not just the Digital Twin which mimics its physical twin but any changes in the Digital Twin are mimicked by the physical twin too’’. [8,5, p.]	Virtual/digital model
Guo, J., et.al. (2018).	‘’Digital twin is the digital mirror of the physical world and maps performance of physical world’’.[53,1, p.]	Digital mirror
Rajratna, K. et.al. (2018)	‘’Digital Twin can be defined as a replication of real physical production system in digital model, which are used for system optimization, monitoring, diagnostics and prognostics using integration of artificial intelligence, machine learning and software analytics with large volume of data from physical systems’’. [54, 7, p.]	Replica
Madni A.M., et.al. (2019)	‘’Digital twin is a dynamic digital representation of a physical system’’.[10,1,p]	Digital representatio n

Source: Authors systematization based on sources in the table

Characteristics of digital twin

The overarching goal is for the digital twin to be self-evolving in the sense that it continuously improves and optimizes its performance in line with the physical system it represents. Digital twins possess a broader set of characteristics that affect their operational and business value.

The first characteristic refers to the possibility of self-adaptation in the sense that it automatically responds to changes in the environment and configuration of its real twin, continuously striving for operational excellence measured by performance indicators adapted to the given case.

Another characteristic relates to self-regulation, ensuring that the changes it undergoes as it adapts to the true twin environment do not exceed the physical twin's limitations in order to maximize its performance measures, such as productivity and throughput.

Thirdly, the digital twin is always aware of the real twin's environment and configuration through self-monitoring of relevant parameters.

Finally, the digital twin is capable of self-diagnosing and evaluating its own health based on current and historical data to identify the reasons for any suboptimal operations.

Besides these characteristics mentioned by Mihai S., et al. [7] , other authors also highlight similar features of the digital twin. For instance, Singh, M. et al. [8] emphasize the fidelity of the digital twin, which refers to being an identical copy of its physical counterpart actually reflecting a high degree of accuracy and reliability in appearance, content, functionality, and behavior. The higher the fidelity, the more significant the impact on the quality of the simulation and the fidelity of the alternative scenarios. The dynamism of the digital twin is achieved through the exchange of dynamic, historical, statistical, and descriptive data in real-time. This, along with fidelity and hierarchy, ensures a realistic emulation of each component of the physical twin. Identification of each physical object throughout its product life cycle with relevant information and their interconnectivity are significant characteristics of a digital twin. The digital twin encompasses the multi-scale and multi - physical nature of the digital twin. Such as shape and size, surface roughness, structural dynamics, thermodynamics, stress analysis, fatigue damage modeling and material properties of the physical counterpart. Furthermore, digital twins possess the characteristic of multidisciplinarity as they integrate various disciplines and serve as the foundation of Industry 4.0.

Classification of Digital Twin

Various criteria, including the lifecycle phases, applications, hierarchy, and maturity level, can be used to classify digital twins into different types. The classification of digital twins is constantly expanding, as the number of dimensions that are taken into account increases with the possibilities of use.

The following Figure 3 shows the division of digital twins according to the available literature.

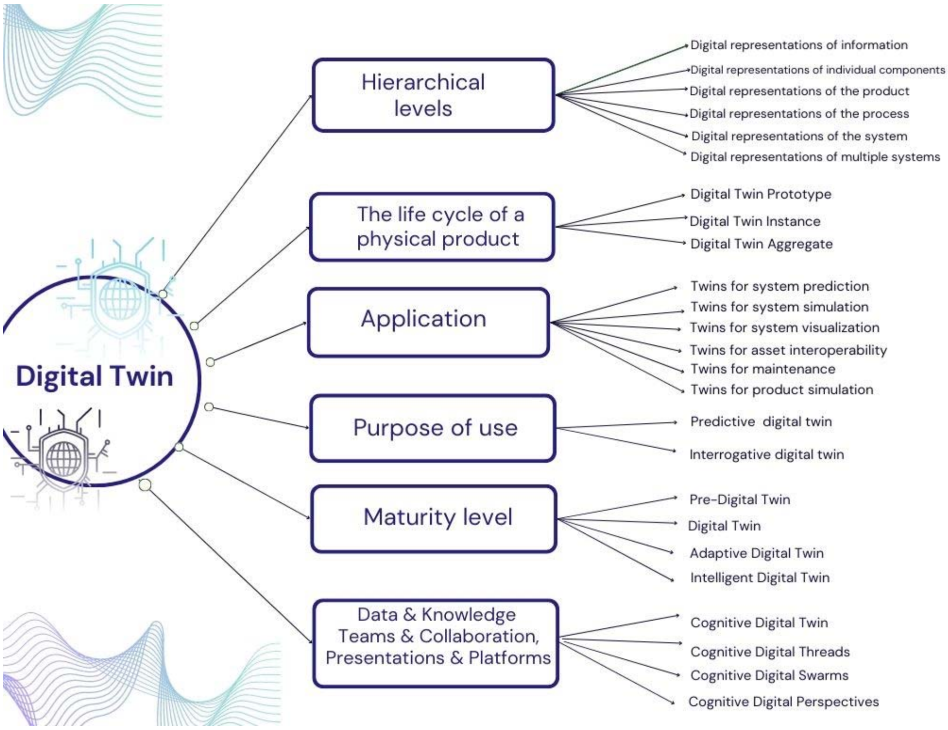

Figure 3. Classification of digital twin

According to IoT Analytics Research [9], digital twins can be classified based on three dominant dimensions: the hierarchical levels of application, the lifecycle phase of usage, and the specific application. These dimensions result in 252 potential combinations, each representing a unique classification of a digital twin.

Digital twins can be classified into six subcategories based on the hierarchical dimension. The informational level encompasses digital representations of information, such as an operation manual in digital format. The component level represents digital representations of individual parts or components of a physical object. The product level relates to digital representations of the interoperability of components at the product level. The process level includes digital representations of entire processes and workflows. The system level involves digital representations of multiple processes and workflows, not limited to physical objects. Lastly, the multi-system level involves digital representations of multiple systems working together as a unified entity. These hierarchical levels enable comprehensive analysis and management of digital twins in various domains and contexts. Digital twins are applied in six lifecycle phases.In the design phase, requirements are gathered and designs are developed using digital twins as a source of data. The build phase involves creating software-based digital twins, eliminating the need for costly physical prototypes. During the operating phase, users utilize online digital twins for tasks like extracting sensor data or remote device control. The maintenance phase involves making changes to hardware, software, and documentation to ensure operational effectiveness. In the optimization phase, existing information is used to improve design, predict performance, and optimize operations. Finally, the decommissioning phase involves removing digital twin releases from use and retiring them remotely.

Based on the area of application IoT Analytics [28] distinguishes the following models of digital twins:

1. Twins for system prediction- used to predict complex systems.
2. Twins for system simulation- simulates complex systems.
3. Twins for asset interoperability- aimed at extracting data in complex systems and creating common data formats.
4. Twins for maintenance-helps maintain the system during its life cycle, enables predictive maintenance to avoid downtime.
5. Twins for system visualization -used for system visualization during the life cycle using 3D visual elements.
6. Twins for product simulation- used during design to simulate the behavior of the product to be developed.

According to sophistication in the level of maturity Madni A.M., et al. [10] listed four types of digital twins. At the first level is the pre-digital twin, a virtual system model created before the physical prototype, with the aim of mitigating technical risks. A virtual prototype is not used to construct the final system, but rather to make design decisions and manage risk in the early stages of the project. It can serve as a prototype to be discarded or reused in later stages of the project. At the second level, a digital twin encompasses the integration of performance, health, and maintenance data derived from its corresponding physical twin. Through interaction between the digital and physical twins, the information acquired from one or multiple digital twins can be harnessed by the physical twin to enhance its real-time performance. At this stage, the digital twin functions as a platform for comprehensive exploration of the behavior exhibited by the physical twin in various hypothetical scenarios, allowing for in-depth analysis and evaluation of potential outcomes. Its executable nature allows for easy manipulation and controlled simulation tests to investigate system behavior comprehensively. Identified deficiencies or shortcomings can be utilized to modify the physical twin. Level 3 introduces the adaptive digital twin, which introduces an adaptive user interface that caters to the needs of both the physical and digital twins, resembling the characteristics of a smart product. The user interface can be customized to accommodate user/operator preferences andpriorities, ensuring a personalized experience. At this level, a salient characteristic is the capacity to assimilate and discern the preferences and priorities of human operators within heterogeneous contexts, thereby enabling a personalized and contextually adaptive interaction. This learning process is achieved through the utilization of a supervised machine learning algorithm, employing a neural network architecture. Theutilization of adaptive digital twin empowers real-time planning and decision-making processes across operational, maintenance, and support activities, facilitating timely and informed actions based on current and evolving conditions. Moving to Level 4, the intelligent digital twin possesses all the capabilities of a Level 3 digital twin, including the incorporation of supervised machine learning techniques. Moreover, this level of advancement introduces the capability for unsupervised machine learning, facilitating the identification and recognition of objects and patterns encountered within the operational environment. Additionally, it enables enhanced learning of system states and environments characterized by uncertainty or limited visibility, thereby augmenting the digital twin's ability to adapt and respondeffectively to dynamic conditions.

Looking at the dimension of the lifecycle of a physical product, authors Grieves M. and Vickers J. [11], have made a distinction between digital twin prototype, digital twin instance and digital twin aggregate. Therefore, a digital twin prototype is a digital twin that contains the set of data and information that is essential to create or manufacture a physical copy of the virtual version. This marks the beginning of the product cycle, and once the digital twin prototype is completed and validated, the production of its physical twin can begin. The more accurate the simulation model used by this type of digital twin, the higher the quality of its physical twin will be. Digital twin instance is a digital twin that describes a specific corresponding physical product to which an individual digital twin remains connected throughout the lifecycle of that physical product. Both types of digital twins are integrated and operated in digital twin environment. Digital twin aggregate represents a collection of digital twins.

According to the purpose of use, the same authors distinguish between predictive and interrogative digital twins. The utilization of the digital twin encompasses the prediction of future behavior and performance of the physical product. Digital twin instances offer the capability to examine their current and past histories, regardless of the physical location of their counterparts worldwide. Individual instances can be interrogated to retrieve information about their present system state. By analyzing data from multiple product instances, correlations can be established to predict future states and outcomes.

Semantic technologies have emerged as critical components in numerous intelligent systems, facilitating semantic interoperability across disparate data and information sources. They offer promising solutions for integrating heterogeneous digital twin models within complex systems that span different

domains and lifecycle phases. By employing semantic modeling and knowledge graph modeling, the integration process becomes more efficient and effective, enabling a holistic understanding of the interconnected digital twins and enhancing the overall system's performance and functionality [12]. By combining semantic technologies with digital twins, El. Adl, A. [13], introduced the concept of a cognitive digital twins as a ‘’digital representation, augmentation, and intelligent companion of its physical twin as a whole, including its subsystems and across all of its life cycles and evolution phases’’.
Taking into account dimensions such as data and knowledge, teams and collaboration, presentations and platforms, the same author defines the following concepts:

1. Cognitive Digital Twin: refers to a purpose-driven digital representation of a physical twin that possesses the ability to continuously acquire knowledge and learn.
2. Cognitive Digital Threads: provides the right data at the right time, within the right context. It involves the integration of data and knowledge for both the physical and digital twins, creating a coherent and synchronized thread of information.
3. Cognitive Digital Swarms: this technical framework focused on the collaboration and interaction between teams of physical and digital twins, allowing for collective intelligence and decision-making.
4. Cognitive Digital Perspectives: it introduced an alternative framework for human-machine interface and man-machine interface that was suitable for cognitive systems, enabling a more intuitive and efficient interaction between humans and digital twins.

One of the most commonly cited classifications of digital twins into subcategories such as digital model, digital shadow, and digital twin, provided by the group of authors Kritzinger W. et al. [14], will not be specifically discussed in this paper due to the increasing criticisms it has received from both practitioners and researchers. The main criticisms of this classification revolve around its recursion, unclear definition of data types, ambiguity regarding why the manner in which data is transmitted should serve as the basis for differentiation, and a lack of utility in practical use [15].

3. Benefits, Challenges and Enabling Technologies

Digital Twin Benefits

Digital twins offer a multitude of benefits that vary based on specific use cases.Here, we will highlight the most important and commonly observed advantages regularly seen in practical applications:

1. **Shortening time and reducing costs in the phases of a product life cycle: -** Simulations enable the exploration of different scenarios, shortening

designand analysis cycles. This makes the entire process of prototyping or redesigning faster and easier. Digital twins utilize virtual resources for their creation, resulting in reduced overall prototyping costs over time. In contrast to traditional prototyping that involves physical materials and labor, digital twin allows for product recreation and testing without additional material expenses. Adamenko D., et.al. [16]state that process monitoring and diagnosis are widely acknowledged as significant benefits of a digital twin in enhancing the quality and identifying irregularities. This, in turn, enables more efficient maintenance strategies that can effectively reduce both costs and duration.

2. **Prediction of issues, improved maintenance, improved product, process, and system planning, prescriptive decision-making –** Digital twins enable the prediction of future issues and errors for the physical twin of a product. This provides the opportunity to plan systems according to anticipated problems, which is particularly useful for products with complex structures and multiple components. Digital twins allow for the optimization of solutions and maintenance strategies for products. Khajavi, S. H., et.al, [17] state a digital twin can provide data regarding the buildings' maintenance needs. Through simulating various scenarios, digital twin provides the best possible solution or maintenance strategy for products or systems. The continuous feedback loop between digital twins and the physical twin enables real-time validation and optimization of system processes.
3. **Mobility and increased safety compared to the physical twin.** - The physical device can be remotely controlled and monitored through its digital twin. Unlike physical systems that are limited by geographical location, digital twin can be shared and accessed remotely. This is particularly useful in situations where local access is restricted. In industries such as oil, gas, or mining, where working conditions are extreme and hazardous, digital twin can reduce the risk of accidents and dangerous malfunctions. According to Kaarlela, T. et.al., [18] the utilization of digital twins allows for the creation of safety training programs that are more effective and visually engaging compared to traditional methods. The ability for remote access and the predictive nature of digital twin can mitigate the risk of incidents.
4. **Improved performance and increased competitiveness of the company** - informed decision-making, risk mitigation, and the exploration of innovative approaches, ultimately leading to improved outcomes and competitive advantages.

Digital Twins challenges

The challenges of implementing digital twins are numerous and can be viewed from various perspectives. Their multiplication is certainly contributed to by the challenges of implementing the technologies of Industry 4.0 themselves, which are actually the technological enablers of digital twins. The most common challenges faced by companies, according to the literature, can be classified as follows:

1. **Investment cost:** Implementing digital twins solutions involves substantial costs for technology platforms, infrastructure development, maintenance, data quality control, and security solutions. Additionally, the ongoing operational expenses for maintaining the digital twin infrastructure can be significant. Attaran, M., & Celik, B. G. [19] emphasize that these high fixed costs and the complexity of the infrastructure will slow the adoption of digital twin technologies.
2. **Data management** refers totechnical, financial and legal aspects of data ownership and governance. Privacy and security pose significant challenges for digital twins in industrial settings due to the large volume of data they utilize and the potential risks to sensitive system data. To address this challenge, according to Fuller A., et.al.[20], it is crucial for the key enabling technologies of digital twins, namely data analytics and IoT, to adhere to up-to-date security and privacy regulations.
3. **IT infrastructure:** Two specific challenges that Fuller A., et.al., [20] discussed are the need for a well-planned IT infrastructure to support digital twins' success and the requirement for high-quality, consistent data to ensure optimal performance of the digital twin.
4. **Connectivity and integration:** The challenges of interoperability arise due to data-level issues, while the integration of digital twin models becomes more complex as a result. Semantic technologies and systems engineering offer potential solutions according to Zheng, X.,et. al.[12] by leveraging advanced tools like knowledge graphs to semantically connect digital models and represent their interrelationships using edges.
5. **Standardized and domain modeling:** Standardized modeling is a key challenge in the development of all types of digital twins, as there is currently no universally accepted approach. A standardized approach is necessary to ensure domain and user understanding, and facilitate information flow throughout the development and implementation stages of a digital twin. Domain modelingis crucial to transfer domain-specific information to each stage of digital twin modeling, ensuring compatibility with domains such as IoT and data analytics.Fuller A., et.al. [20] notice that this enables the effective utilization of the digital twin in various applications.
6. **Reliability and rate of synchronization:** The reliability of the virtual representation and the synchronization rate depends on the purpose of the digital twin. According to Mihai S., et al. [7] in certain applications, such as surgery or the aviation industry, high levels of reliability and synchronization are necessary. However, for traffic management and 3D visualization purposes, lower levels of reliability and synchronization can be sufficient.

7. **Cognitive capabilities:** The primary challenge facing Cognitive Digital Twins (CDTs) is achieving cognitive capabilities. Abburu S., et al. [21] identified three key challenges in CDT cognition: knowledge representation, knowledge acquisition, and knowledge updating. Knowledge representation refers to defining and standardizing relevant information and knowledge as input to digital models to ensure interoperability. For the representation of domain knowledge, existing domain standards, and collaboration between digital twins, the authors propose an ontology, and for the representation of problem-solving knowledge certain rules. Another challenge is gathering implicit knowledge, which is based on personal experience. NLP technologies such as text mining and speech recognition can help. In order to discover hidden knowledge from raw data following the flow of data-information-knowledge, data mining can also be used. Knowledge update is an ongoing process of continuously updating existing knowledge and generating new knowledge. It encompasses knowledge extension, knowledge forgetting, and knowledge evolution. The main challenge is to maintain consistency after implementing changes and, more importantly, to identify the right timing for incorporating changes. In addition to this limitation of the cognitive digital twin, Zheng, X.,et al. [12] also point out the challenges of integrating digital twins, the lack of standardization, and implementation difficulties.

Digital twin enabling technologies

Digital twins require specific enabling technologies that vary depending on the intended use case. One crucial aspect is establishing a communication medium between the physical and digital twins. The selection of enabling technologies for digital twins involves careful consideration of communication protocols, algorithms, and frameworks that align with the specific requirements and objectives of the digital twin application. However, the choice of communication protocol depends entirely on the communication requirements of the specific digital twin application. Researchers and practitioners from diverse industries analyze and choose technologies that best suit their use cases to effectively develop and utilize digital twins in their endeavors.

The most common enabling technologies of the digital twin are illustrated in Fig. 4.

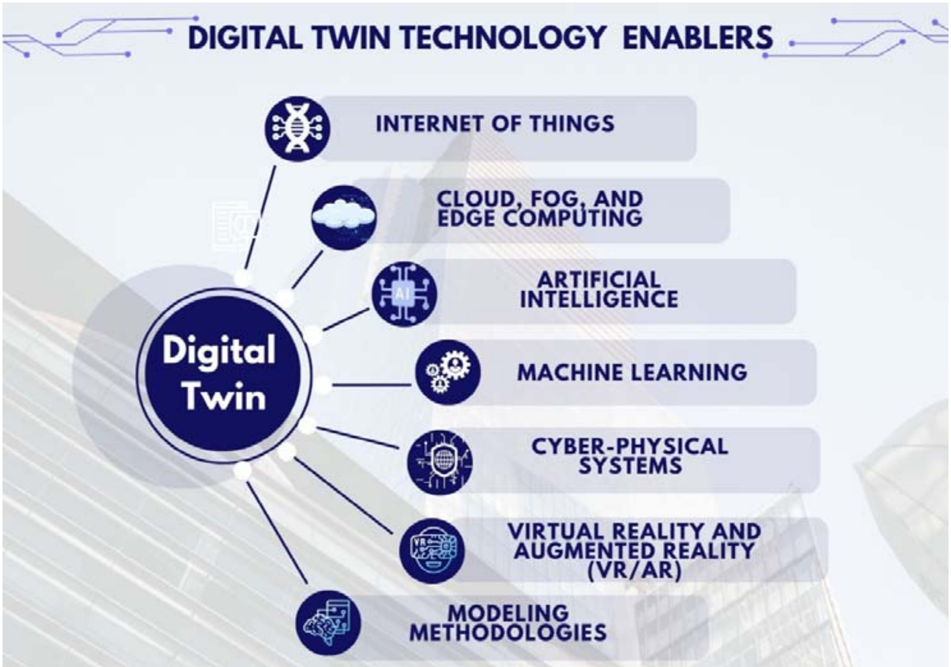

Figure 4. Digital twin: Enabling technologies

By leveraging AI/ML models, digital twins can replicate the behavior, characteristics, and interactions of their physical counterparts. This leads to a more detailed understanding of the underlying processes, as well as the ability to predict, optimize performance and support decision-making.

Cloud computing refers to the delivery of IT resources, including data storage, computing power, networking, and software, over the internet. Cloud computing plays a crucial role in the implementation of digital twin systems by providing a cost-effective and efficient solution without the delays typically associated with building infrastructure from scratch. Fog and edge computing provides a distributed computing infrastructure that complements cloud computing in the context of digital twins, enabling localized data processing and privacy preservation. In this case, not all data is transferred to the cloud and sensitive or critical data can be processed locally, ensuring data security and reducing bandwidth requirements. This is especially important in applications where privacy, security and compliance are crucial. They enable real-time processing, efficient use of resources, localized data processing and improved responsiveness.

The Internet of Things enables the seamless and real-time exchange of data between a multitude of physical devices via the Internet. Although a huge network, it is able to simplify the connection between physical entities and their virtual representations. The basis of the IoT ecosystem is made up of smart sensors whose role is the integration of traditional sensor technology with microprocessors and/or wireless communication units. This integration enables smart sensors to collect environmental data with precision and automation. By combining data collection capabilities with intelligent processing and communication functions, smart sensors contribute to accurate and efficient data collection, facilitating the development and use of digital twin systems. VR and AR technologies provide immersive and interactive experiences for physical-virtual twins. They enable visualization, communication and manipulation of virtual representations of physical systems, improving the understanding and control of complex processes. The use of VR/AR makes digital twins more accessible, engaging and efficient, as users can monitor critical data, explore virtual environments and operate equipment with the help of intuitive virtual interfaces.
Modeling enables the representation and management of physical entities in digital form. Geometric, physical, feature, behavioral, and rule modeling techniques are utilized to capture various aspects of the physical entity and facilitate analysis, simulation, reasoning, and optimization within the digital twin framework [22]. Geometric modeling focuses on capturing the geometric information of an entity, while physical modeling incorporates additional details such as accuracy, material properties, and assembly information. Feature modeling involves defining interactive features, automatically recognizing features, and enabling feature-based design. Behavioral modeling encompasses the representation of various behaviors exhibited by a physical entity to fulfill functions, respond to changes, interact with other entities, and adjust internal operations. Simulating physical behaviors involves multiple models, including problem models, state models, dynamics models, and evaluation models. Rule modeling involves extracting rules from historical data, expert knowledge, and predefined logic to equip the virtual model with reasoning, judgment, evaluation, optimization, and prediction capabilities. Rule modeling is a demanding task because it includes rule extraction, rule description, rule association, and rule evolution.

Digital Twin Platforms
Due to the costly and complex nature of digital twin development, technologically advanced companies offer platforms to assist other companies in developing their own digital twins for products, processes, or systems. These platforms provide valuable support and resources for organizations seeking to

embrace the benefits of digital twin technology. The following section offers some information on these companies.
The Siemens digital twin platform, ‘’Xcelerator’’ allows companies to create digital replicas of their products and systems, optimizing performance, reducing costs, and improving efficiency. Sweden’s NEVS utilizes the Siemens Xcelerator platform to establish a digital thread and comprehensive digital twin for vehicle projects, emphasizing the significance of advanced simulation technology and a digital twin approach in creating safe self-driving mobility solutions. The outcomes include leveraging enhanced digital twin accuracy for sustainable mobility solutions and achieving a 50% reduction in initial vehicle assessment time, automation of simulation processes, and an 80% reduction in early-stage design option identification time [23].
The General Electric platform ‘’Predix’’ enables companies to create and manage digital twins of their products, processes and systems and to analyze data from those twins to improve performance and efficiency. The primary focus of this platform lies in industrial applications, providing a range of tools specifically designed for constructing digital twins of industrial assets like turbines or factories. By using this platform, users can enable predictive maintenance, optimize performance, and gain valuable operational insights [24].
One perfect example of the utilization of digital twins in warehouses, particularly with NVIDIA Omniverse, has been instrumental in revolutionizing Amazon Robotics [25].By creating full-scale digital replicas of their warehouses, they have been able to optimize warehouse design, train intelligentrobot assistants, and achieve operational efficiencies. The ability to simulate and understand the performance of warehouses before their physical construction has been crucial in scaling Amazon’s complex operations. They have successfully aggregated data from various CAD applications and visualized massive models with exceptional realism.
Microsoft’s Azure digital twins is a platform that allows the development of twin graphs representing complete environments, ranging from buildings and factories to cities. These digital models offer valuable insights for improved product development, optimized operations, cost reduction, and enhanced customer experiences. An example of digital twin utilization can be seen in Rolls-Royce’s management of over 13.000 commercial aircraft engines. These engines are equipped with numerous sensors that provide telemetry data on engine health, performance, fuel usage, and service requirements. To handle this vast amount of data, Rolls-Royce employs a digital twin solution built on Microsoft Azure, which enables a digital feedback loop for product updates, optimized maintenance processes, and real-time monitoring of the entire engine fleet during flights. This technology has enabled Rolls-Royce to offer its ‘’Power by the Hour’’ service, creating a new business model that lowers costs for airline customers [26]. Kongsberg’s dynamic digital twin integrates safety,

rapid prototyping, and implementation, connecting offshore and onshore users in the oil and gas sector. This digital twin is based on KognifAI, an open digital ecosystem platform that provides digital twin solutions across multiple industries, including maritime, drilling, wells, and renewable energies [27].

4. Applications Across Industries

Many authors have explored the use of digital twins to uncover the benefits and challenges encountered in their development and implementation. The literature mostly focuses on reviewing existing studies on digital twins, with some works demonstrating their practical application, and fewer case studies specifically address the creation of virtual products, processes, or systems, as digital twins are referred to.

As the application of digital twins becomes increasingly certain yet challenging in various industries, exploring the areas where they can be applied proves beneficial. Most applications of digital twins are in the following industries:

1. Manufacturing: digital twins can be used to optimize production planning and recourse allocation, simulate production process, optimize industrial human-robot collaboration, monitoring and prognosis production tools, optimize warehouse management [29], monitoring of machine performance enabling early issue detection and prediction, enhances connectivity and feedback among devices, and improving reliability and performance [20]. As an example of a digital twin for process automation (autonomous driving), the simulation of automation in BMW can be highlighted [30]. Autonomous driving is a significant source of competitiveness in the automotive industry. The technical solution for autonomous driving is a highly complex task, requiring a large number of engineers working on one product, within a vast software repository, and addressing various scenarios that need to be anticipated. Engineering challenges can be optimized by leveraging digital twin simulation platforms, combining simulation with statistics and scenario analysis to overcome the extensive validation efforts required.
2. Oil and Gas Industry: According to Wanasinghe, T.,et.al. [31] the most common areas of use of digital twin in the industry are: asset monitoring and maintenance, project planning and life cycle management, drilling, offshore platforms and knowledge sharing, pipelines, marine vessels, virtual commissioning, virtual learning and training, and intelligent oilfields. An example of the use of digital twins for offshore installations, given by Sentient and Holis [32] shows challenges and solutions in designing digital twin for oil company. The most significant challenges that needed to be overcome were ineffective monitoring methods, lack of centralized key information, cost and time implications of transitioning to a new platform. As a solution, they developed a full digital replica of the platform containing all

the available equipment data that was intuitively navigable by a user through a web application.Digital twin increased yield, reduced unplanned downtime, improved workforce efficiency and safety, real-time monitoring, improved decision-making, and discovered additional avenues for profit-making and uplift.

3. Aerospace: Most common use case for digital twin is refer to design customization, prediction of the life of aircraft structure and assuring its structural integrity [30], optimization of the transport load [34], virtual testing or simulation. Boeing, among other companies in the aviation industry, has embraced digital twin manufacturing. By implementing the digital twin asset development model, Boeing has successfully achieved a remarkable 40% enhancement in the initial quality of parts and systems used in airplane manufacturing [35]. This is accomplished by utilizing ultra-high-fidelity simulation software, which helps to create a virtual three-dimensional model that can simulate the lifecycle of the asset, including the environments and conditions it will encounter.
4. Building and Construction: digital twin is used for evaluating space capacity and smart design, structure safety monitoring [36], virtual prototyping and verification, building management and quality control, optimizing project processes, and automated project control. One example of predictive digital twins for real-time monitoring and maintenance was used by the Norwegian Public Roads Administration, to predict damages to bridges [37]. They use IoT sensors for detection and behavior on bridges. Data is collected on the cloud, and if bridge dynamics deviate from the present thresholds system issues alerts. This reduces emergency maintenance costs, creates proactive and predictive maintenance, and rely on knowledge and data road management.
5. Medical and Healthcare – most common use for digital twins in healthcare refers to optimizing elderly healthcare services, diagnosis, and therapy, preventive treatment, drug development, medical device utilization, education and training, surgery, or medical simulation. According to Liu, Y., et.al. [38]healthcare simulation mainly focuses on healthcare education, healthcare mechanical simulation, resource allocation optimization and business process simulation, and clinical trial simulation. Barbiero, P.,et.al. [39], proposed a model of digital twin for a panoramic view of the whole body for preventive purposes. That model is based on artificial intelligence, mathematical models, and neural networks. So far, it has been tested in two clinical studies. In addition, one of the examples can be a digital twin model for detecting and predicting causes of thrombosis, based on a simulation of the flow of blood through the heart presented in the work by Shang, J. K., et.al., [40].

These are just some of the use cases in specific industries, but we can expect the development and utilization of digital twins to grow not only within industries but across the entire ecosystem. A prime example of this is the emergence of virtual cities, where digital twins can be instrumental in modeling and simulating urban environments [41,42], leading to improved planning and decision-making processes [43-56].

5. Use Case in the Elevator Industry – Schindler Company

Schindler is a global elevator and escalator company, providing solutions for vertical and horizontal transportation systems for buildings of all sizes, types and forms. It has more than 69.000 employees in 100 countries around the world. They cover the full life-cycle – from planning, sourcing/manufacturing, installation to maintenance and modernization.Schindler has been working on digital twin concepts since 2017. In the recent years it has started working on digital transformation, which is going beyond enabling the digital twin technology. The adoption of digital twin technology represents a paradigm shift in work practices, requiring significant alterations in the interaction with diverse artifacts, including documents, materials, products, and data. This transformative approach necessitates substantial modifications in associated processes throughout the entire lifecycle, encompassing activities such as development, industrialization, validation, training, and maintenance. Following initial feasibility studies, the initial productive implementation of digital twins has been achieved in the domain of escalators.

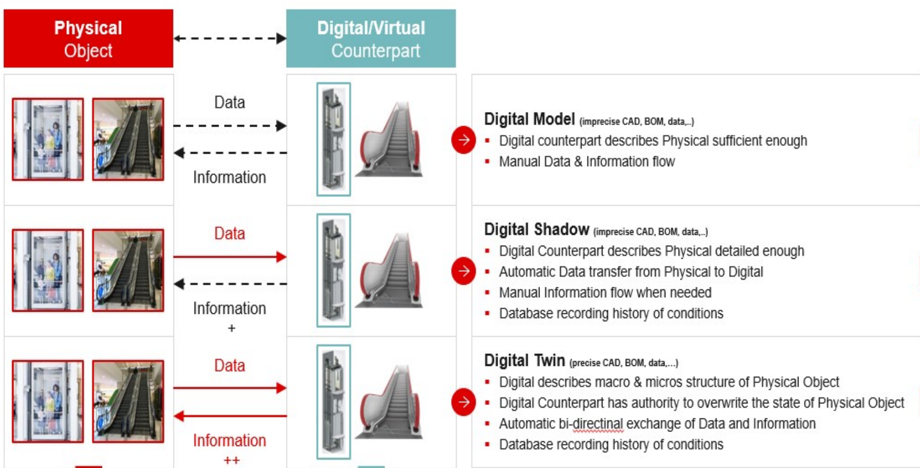

Figure 5. Physical connecting virtual; division into three categories depending on integration level by Schindler

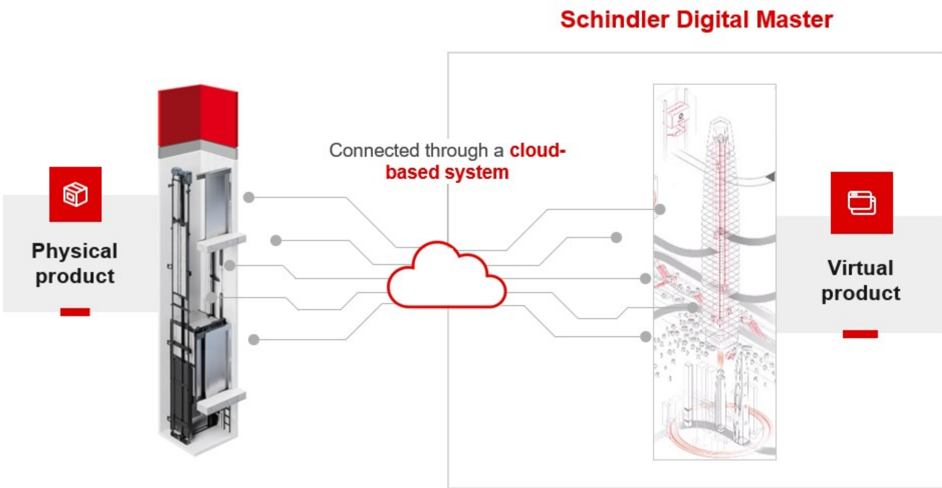

Figure 6. Digital twin of the elevator by Schindler

Leveraging the successes of this initial deployment, ongoing endeavors are underway to extend the application of digital twin technology to the elevator business.

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In Fig.7., the digital twin is described as a data-driven architecture that links together information generated from across the value chain and product lifecycle at any instance of time.

In the first phase of the product lifecycle, called requirements engineering, all product requirements are defined (such as height, number of floors, motor power, number and type of parts, material sources, etc.) based on its intended purpose (e.g., residential or commercial building, hospital, skyscraper). This is followed by the digital representation of these requirements, and then the 3D design of the configurable product, which includes both standard elements and customizable elements (e.g., stair length). Subsequently, product simulation is conducted using a 3D mathematical model, utilizing various tools and analyses such as Failure Mode and Effects Analysis (FMEA), mechanical and material analysis, oscillation, vibration, etc.

The result of this simulation is a highly detailed model for each part, ensuring product functionality. The benefit is the significant reduction of costs associated with prototype construction and testing.

Figure 7. Digital twinlifecycle by Schindler

In the ‘’as delivered information’’ phase within the integrated system, the model or part is sent to the production machine (e.g., laser cutting machine) for manufacturing. The ‘’quality collaboration’’ phase involves virtual reality (VR) training of employees for product installation, while simplified 3D models and work instructions provide manuals for installation, maintenance, defect detection, and control (including ergonomics and malfunctions).

Through the use of IoT devices and remote monitoring, which track the functionality of the installed product and collect data for analysis, preventive maintenance is enabled.

Digital Twin technology and service providers are offering support to start with, however, in the end, for large organizations with different platforms and many legacy systems and processes, it is still their own task to go through the digital transformation.

Main challenges are (1) in transition from ‘’old’’ to new, that is in strategy and procedures to migrate and keep operational in the same way. This requires one the one hand dedicated resources, and other large investments into implementation and migration projects. Once the decisions for investments are made, the implementation challenge (2) of choosing the right partner(s) is coming on-board. Supplier base is large, but very few providers fit ‘’exactly’’ into the target business model and the industry. That means that lot of effort is to be spent to ensure good cooperation and optimal services from the chosen provider(s). The fact that the technology standards in the area are not yet established is an additional factor to be considered. Last but not the least (3), even most important is the challenge related to motivating the employees to change their way of working. The main drive for this is good and consistent communication and making sure that the change is good for everyone.

In Figure 8., the right side depicts the existing infrastructure with various applications and domains in which they are used. Integrating these applications is a key challenge in building a digital twin. The left side of the photo illustrates how product and object changes are managed prior to product manufacturing. Cloud technology serves as an enabler in constructing a digital twin due to the complexity of operations and geographical dispersion of business.

Schindler has been maintaining the data on different platforms suitable for particular parts of the value chain (e.g., one for the development of 3D models and exchange with the CNC machines and another for transaction processing the equipment tests before putting into operation or regular maintenance, etc.). With the Digital Twin approach, the need for a common platform or platform suite has increased.

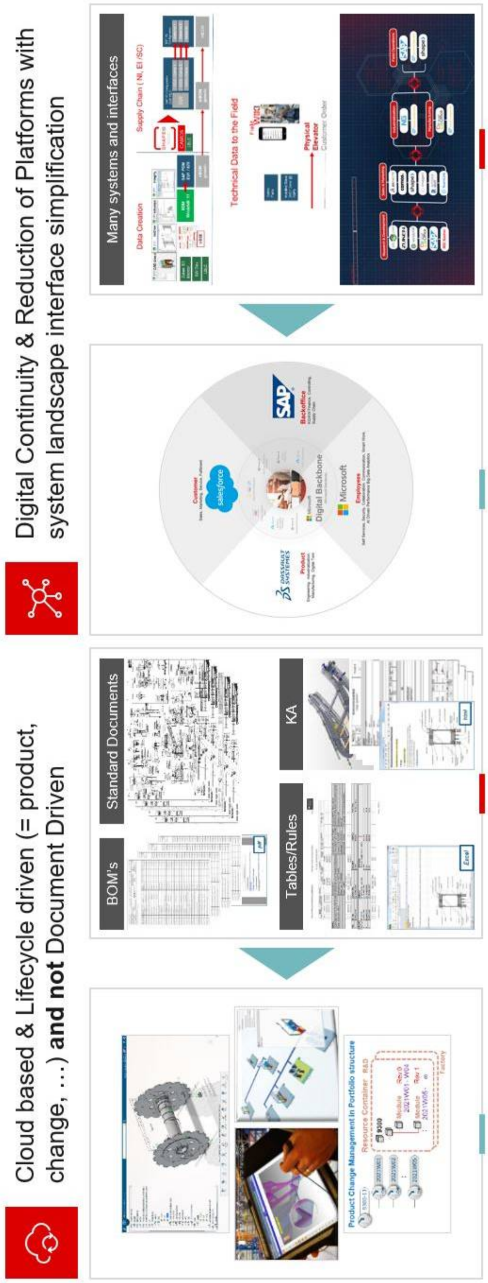

Figure 8. Cloud based product lifecycle management with digital continuity and reduction of platforms by Schindler

The vendor chosen to provide the main parts of the platform in the current phase of Digital Transformation is Dassault, a company having a background in the aeronautics industry, where from they have derived knowledge and experience in 3D & business process modeling.

Figure 9. Digital twin platform for integration by Schindler

Digital twin provides Schindler with many opportunities to simulate not only the actual product, but also their manufacturing, installation and full operation. It provides sustainable and cost saving methodology and tools to simulate different scenarios and prevent from potential failures. Due to the built-in guidance by the implemented tool, it provides at the same time more adherence to the defined processes, as well as excellent collaboration platform for teams across different development and manufacturing sites around the world.

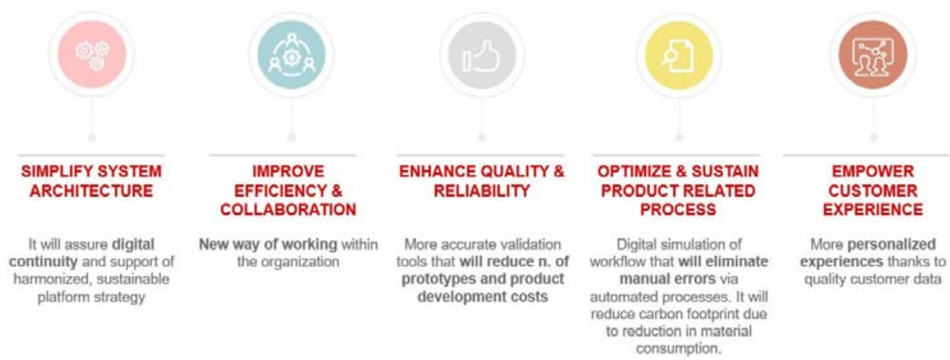

Figure 10. Digital twin benefits by Schindler

6. Conclusion

Digital twins are revolutionizing industries by providing a digital representation of physical assets and systems. As technology continues to evolve, digital twins will play a vital role in driving innovation, efficiency, and sustainability in the digital era. Embracing digital twins offers organizations a competitive edge in the digital era and opens up new possibilities for innovation and growth. Additionally, the connection between digital twins and the metaverse presents exciting opportunities for innovation. By linking multiple digital twins in a single environment, companies can build the foundation of the industrial metaverse, facilitating seamless interaction and collaboration between virtual and physical worlds.

It is expected that future research on digital twins will move in the direction of solving the key challenges identified in their implementation in organizations. First of all, the challenges in improving the integration of data and real-time analytics, by exploring the new possibilities of advanced techniques such as machine learning and artificial intelligence for real-time monitoring, as well as the use of predictive analytics. Scalability and interoperability challenges must be addressed to enable seamless integration and interaction between digital twins across different systems and organizations. Secondly, by exploring innovative human-digital twin interaction paradigms, such as augmented reality and natural language processing, thereby improving user experience and control. Thirdly, the ethical and legal issue of privacy, security and data ownership is an area that still has a lot of room for improvement. In addition, the sustainability and environmental impacts, as well as the socio-economic effects of digital twins on organizations and the workforce, require further research.

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Comparative Analysis of Digital and Traditional Marketing in the Market of Bosnia and Herzegovina

Maida Eljazović*1, Amel Kosovc[2], Elma Avdagić-Golub[2]

Abstract: *With modern technological progress and scientific achievements, companies are actively adjusting their business strategies in order to take advantage of new business opportunities and achieve maximum profit for their companies. One of the current changes in the field of marketing is the increasing emphasis on digital marketing. Digital channels, such as social networks, mobile applications and online advertising, are becoming essential tools for communication and engagement with target audiences. Mobile applications, m-commerce and other innovations allow consumers to easily buy products and access information about brands anytime, anywhere. This trend requires companies to be active on digital platforms and adapt to the mobile experience in order to achieve success in the market. In the decision-making process, it is important to have the best possible analysis so that the strategy is as good as possible. SWOT analysis of digital and traditional marketing through strengths, weaknesses, opportunities and threats gives clear facts about how marketing is developing in the modern market, especially in Bosnia and Herzegovina. This paper provides an analysis and comparison of digital and traditional marketing with the aim of understanding their strengths and weaknesses in the market of Bosnia and Herzegovina.*

Keywords: *digital marketing, traditional marketing, social networks, advertising, media, magazine, swot analysis.*

1. Introduction

Marketing involves promoting the business and connecting the company with the target audience. The main goal of marketing is to direct the attention of users through various promotional activities. We distinguish between traditional and digital marketing. Traditional marketing uses conventional methods for advertising and promotion in order to achieve the desired goal of business, selling products and services [1]. It conducts its marketing activities through direct sales, which includes: press, radio and television ads, banners, billboards, etc.

*1Nelt Ltd., East Sarajevo, B&H
[2]University of Sarajevo, Faculty of Traffic and Communications, Zmaja od Bosne 8, 71000 Sarajevo, Bosnia and Herzegovina
E-mail: maida.eljazovic@fsk.unsa.ba

Digital marketing refers to all activities undertaken to advertise, promote and sell products or services of a brand on online platforms [2]. Digital marketing is a set of activities that are set up and carried out on the Internet with the aim of advertising, promoting and ultimately selling products and services to users on the Internet [3]. Digital marketing is the result of changes in the social and business environment, among which we highlight: increased mobile presence in everyday life, personalization and targeted advertising, social media, enhanced video content, and others. The use of digital channels enables full insight into statistical data, which significantly affects the development of marketing companies, as well as better offers to potential advertisers and clients.

The transformation of business models as part of Industry 4.0 has resulted in various improvements in companies, as well as in marketing processes, which leads to increased profits, reduced costs, easier market analysis, improved customer experiences, innovations, etc.

The aim of this paper is to investigate and analyze marketing in the FMCG (Fast-Moving Consumer Goods) industry in the market of Bosnia and Herzegovina.

For the purposes of this research, the data will be provided by the marketing company Altermedia, which is the founder of InStore magazine, and which operates on the market of Bosnia and Herzegovina. We will analyze the results of the marketing campaign from the aspect of using traditional and digital marketing methods.

2. Overview of Previous Research

Digital marketing encompasses a wide range of methods and techniques used to promote and advertise products or services through digital channels. The most frequently used methods, which we included in our research are:

- SMM (Social Media Marketing)
- SEM (Search Engine Marketing
- SEO (Search Engine Optimization)
- PPC (Pay-Per-Click)
- CM (Content Marketing)
- E-mail Marketing

Social Media Marketing (SMM) is the advertising of a company, products or services using online platforms such as Instagram, Facebook, TikTok, LinkedIn, Twitter, etc. In the papers, the authors analyzed the importance of social networks on digital marketing as well as on the psychology of people, which has a significant impact when choosing a certain product. They deal with the issue in detail and talk about social networks and social media that have become the main component of the virtual world as a powerful tool for all types of group dynamics and crowd psychology[4]. Social networks are part of a social structure that is made up of mutual connections, organizations or individuals that have common interests. This form of media is changing day by day and what started for the purpose of leisure and private use has grown into a business that companies use to advertise, but also to collect the necessary information necessary for further business [5]. The idea of this type of promotion is to reach a wider mass of people, which is the target group, in order to build a community and gain their trust. Visiting social networks has become our daily routine. Statistics show that 52% of the population in Bosnia and Herzegovinauses social networks [6]. When it comes to promotion in the FMCG industry, through the observed magazine, the most common requests from clients and companies are for posts to be visible on Facebook or LinkedIn platforms.

Another method used is Search Engine Marketing (SEM), with which the agency creates paid campaigns, which are mainly placed within the search results. This method includes paid-to-display ads that charge for user clicks or views. Researchers have identified the web as the first port of call for information search. Search engine marketing (SEM) strategies have been noted as key factors in the development, maintenance and management of websites [7].Search Engine Optimization (SEO) represents a combination of several methods in creating a website, creating content for the website, and obtaining external links from different websites, which have the ultimate goal of positioning the website or individual pages on the first page of Google search[8]. The authors used this method and investigated variables such as market share, brand loyalty, brand recognition, product price, product information, brand image, brand awareness, online consumer behavior, etc. Placement on search engines has become a key task for those involved in website marketing because good positioning in search engines significantly increases visitor traffic. In the works of researchers of this method, it was determined that SEO practice is diverse and that its application is not universal. Not all organizations make the most of SEO, although some publishers have a very sophisticated approach. Efforts are limited by time, resources and management support, as well as technical problems [9].Pay-Per-Click (PPC) is a digital advertising model where an advertiser pays a fee every time one of their ads is clicked. Basically, it pays for targeted visits to a website or any other digital location. According to Altermedia company, brand awareness increases by 30% to 50% in this way.
The PPC advertising approach is based on competitive bidding among commercial advertisers. This type of digital marketing strategy is also called Cost-Per-Click (CPC) advertising [10].
Content Marketing (CM) represents a long-term strategy focused on building a stronger connection with existing and potential clients, and a stronger online presence and market position. The ultimate goal is to expand the customer base and achieve loyalty and ultimately greater profits. Content marketing is

amarketing method that involves consistently creating quality content for the purpose of attracting, engaging and retaining an audience. The research results reveal that regular measurement of the success of content marketing and the use of the obtained data as guidelines for improving thecontent have positive impact on the effectiveness of content marketing andbusiness results [11].

E-mail Marketing is used when the advertiser wants to send his promotional message via e-mail to previously known addresses and target users. A common form of e-mail marketing is newsletter marketing. Newsletter e-mails usually contain promotional campaigns such as a special price for a product, free shipping or discounts on purchases. E-mail marketing is the oldest form of marketing, but it is still used and has significant results in campaigns [12].

Traditional marketing refers to the traditional methods of advertising that were used before the appearance of digital marketing. These methods are often based on direct communication with the target audience through traditional media. When it comes to traditional marketing methods, research is based on:

- TV and radio advertising,
- printed media (daily newspapers, magazines, etc.),
- printed materials (leaflets, brochures, catalogs, etc.),
- recommendations (Word of Mouth),
- fairs and presentations,
- billboards and posters.

Although traditional marketing plays an important role in reaching the local audience, the authors of the paper [13] point out that in the modern world it has become increasingly difficult for an organization to survive in the competition if it decides to use traditional marketing methods. Therefore, organizations try to adopt new technologies in order to meet and satisfy clients' needs and desires. Since the beginning of the 21st century, there have been drastic improvements in information technology that affect every part of our lives. Companies are affected by these changes and adopt new technology to stay competitive. The integration of traditional and digital methods can create a complete marketing strategy that targets different segments of the target audience and takes advantage of both approaches. In this regard, SWOT analysis can be a useful method for comparing traditional and digital marketing. SWOT analysis represents the identification and assessment of strengths, weaknesses, opportunities and threats. It is intended for obtaining strategic insights [14]. It can be applied to any field and that is the reason it is very often used in decision-making. SWOT analysis enables a structured approach in identifying key factors for each of the marketing methods, and can help in understanding their advantages and challenges. Based on these insights, marketers can design an integrated strategy that maximizes the strengths and minimizes the weaknesses of both approaches.

3.Analysis of Marketing in the Market of Bosnia and Herzegovina

3.1 Dataset

The research used data from the company Altermedia, which implements campaigns in the FMCG industry through its InStore magazine as well as other forms of marketing.
InStore magazine is a monthly trade magazine of the agency Altermedia on fast-moving consumer goods (FMCG). It covers the entire FMCG industry, organized and traditional trade and wholesale, manufacturers and distributors of consumer goods (including alcohol and tobacco products), supporting industries (IT, equipment, finance), as well as regulatory bodies, institutions and market research agencies. It is distributed free of charge by mail to each recipient separately.
This magazine consists of:

- local/regional/world news;
- new facilities locally/regionally;
- opinions and comments of trade experts;
- interviews with the most prominent professionals from the FMCG industry;
- special supplement Guide through the selected category and special analysis of categories (InFokus));
- analyses of research agencies;
- special topics and editions (100 must have products, Made in Bosnia and Herzegovina).

The magazine holds advertisements for brands, companies and services which deem it important for their novelties to be seen by key people in the industry. Considering the more difficult power of control over who actually takes over the magazine, as well as due to the frequent change of positions within organizations, this method is not the best if we want to assert who actually reads it, what their position is, but also what they usually focus on in order to develop in that direction. Due to all of the above, in addition to the printed edition, a digital edition was also launched, as well as content placement on the website and social networks.Altermedia is divided into two divisions: B2B (Business-to-Business), which is business between organizations and B2C (Business-to-Consumer), which customer-oriented business. In addition to the BIH market, the company also operates in Slovenia, Croatia, Serbia and Macedonia.
When it comes to traditional advertising methods, in addition to the InStore magazine that is distributed in print, Altermedia also carries out traditional marketing activities through various activities. Some of the important projects are: Sarajevo Marketing Summit, FMCG Retail Summit, Social Media Summit,

Must Have, I BiH Green, InHoReCa fair, Business Leadership Conference, Talk in Business conferences, Ladies In Events, and Ladies In Awards.

3.2. Analysis of digital marketing in the market of Bosnia and Herzegovina

To understand the success of marketing efforts, in terms of attracting new audiences and building long-term relationships with users, we analyzed user visits to the site (web portal), which is shown in Figure 1. The figures that display visitors, new users and returning users provide insight into the effectiveness of marketing activities and attracting new audiences to the portal. The Figure indicates that the page was viewed by 14,854 users, 4,276 of which were users who had already visited the portal, while 4,070 users were new visitors. It is important to note that the readers are loyal, which can be seen from the data analysis. As many as 75.8% of visitors return to the portal, which indicates a high level of user trust and satisfaction with the content provided. This information is crucial because it indicates success in keeping existing audiences and building loyalty. Knowing that 4,070 users were new visitors indicates the success of marketing efforts in attracting new users and visitors to the portal. This data can also serve as a basis for further marketing strategies. For example, given the high percentage of returning visitors, one could consider investing more in user retention activities and providing personalized content that will further enhance their experience on the portal.

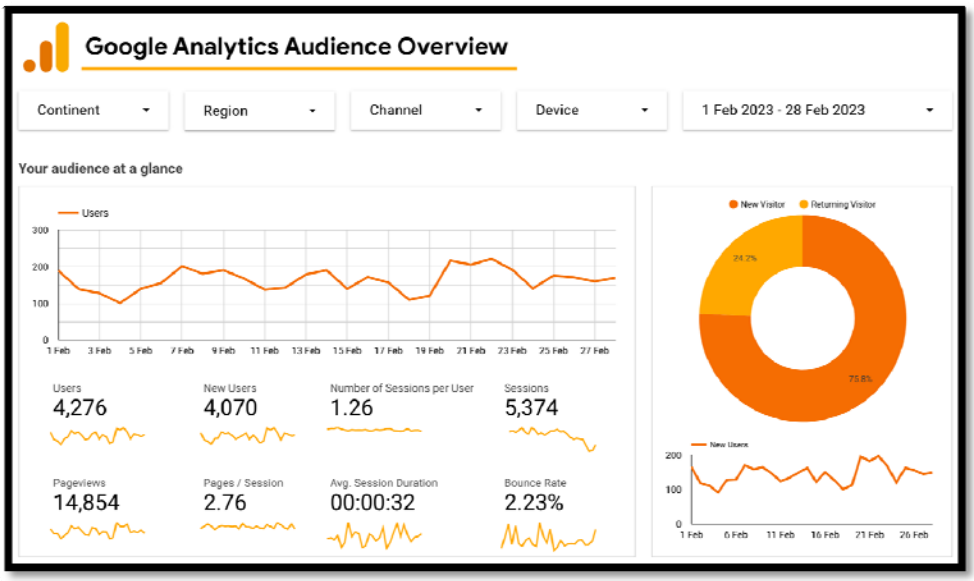

Figure 1.Overview of web portal users

Figure 2 shows the possibility of tracking additional information that can provide a deeper insight into the portal's audience. This information includes the type of device visitors most often use to access the portal, information about the continents they come from and the language areas they belong to. Display of device type data enables understanding of audience preferences regarding access to content. It can be seen that the majority of visitors use mobile devices, 65.9% of them. This indicates the importance of optimizing a website for mobile platforms. On the other hand, 24.2% of visitors use desktop computers.

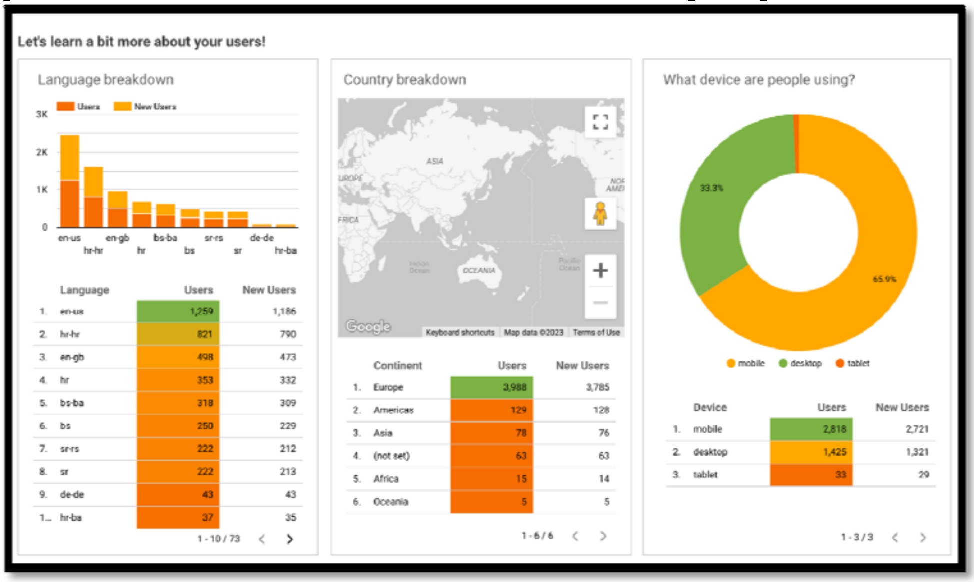

Figure 2.Overview of the web portal audience

When it comes to promotion in the FMCG industry, the most common requests from clients and companies are for posts to be visible on social networks Facebook or Linkedin.

Facebook is the world's largest social network and the most popular among advertisers. It has an excellent targeting system for finding the target audience. It is currently the most visited site in Bosnia and Herzegovina.

Facebook is a social network for a wider audience, and important news is usually published there, both to business people and to all those who need to have information about new products, services or just to be generally informed about events in consumer goods industry.

Service users are increasingly demanding the monitoring of statistics on the visitation of published ads, images or advertisements in order to better understand their effectiveness and success. The following figures (Figures 1-4) provide important information about the number of visitors, date, gender, age, number of views or interactions with the published content. This data allows marketers to track how often content has been viewed and interacted with. In our data, the highest number of views is 8539, and that the most frequent visits are in the second and fourth weeks of the month. Figure 4 provides information on the gender and age groups of visitors. This is useful for understanding the demographic profile of the audience that interacts with the published content. Knowing the gender and age groups of users allows for the adjustment of marketing strategies in order to better target the appropriate audience. The most frequent visitors are women, 63.2% of them.

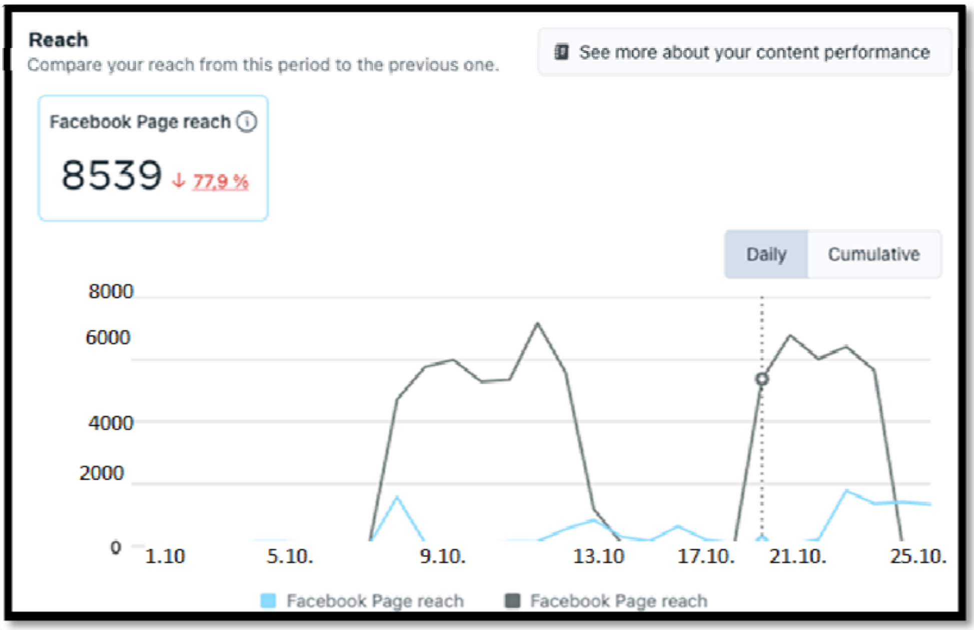

Figure 3.Statistics on portal visits

Another feature of digital marketing methods is insight into user activities, providing data about their preferences and habits on social networks, which is visible in Figure 3. We see that information about user activities is displayed, including the period in which they are most active and which content is the most liked. This data helps determine the optimal times to post content and understand audience preferences.

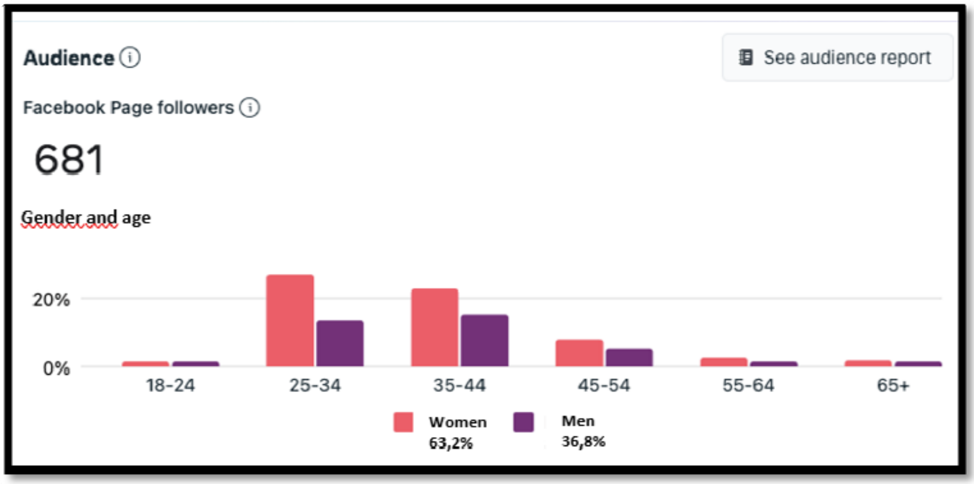

Figure 4. Audience gender and age

In addition, identifying the most popular information or content that is liked the most allows to focus on creating similar content that attracts the interest and engagement of users (Figure 5).

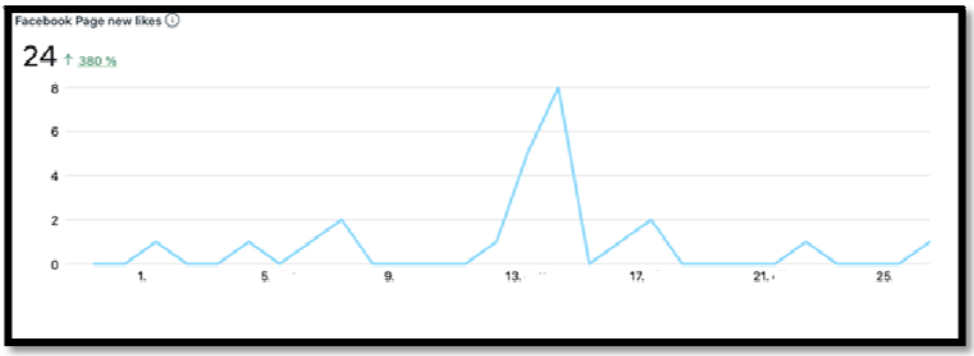

Figure 5. Page view of new likes

In addition to the above information, there is also the possibility of tracking additional details to better understand the audience and their interests. Figure 6 and Figure 7 provide information about the geographic location of website followers. This includes information about the city and country the followers are from. This data is of great importance for tailoring content and marketing messages to specific target markets. Understanding the geographical distribution of followers enables personalization of content to better suit their local preferences, culture and language needs. We see that the most frequent readers are from Bosnia and Herzegovina, namely from cities of Sarajevo, Mostar and Tuzla.

Figure 6.Geographical position of followers

Figure 7.Geographical position of followers

LinkedIn stands out as an excellent channel for communication and exchange of information from the business environment. Through the statistics and analytics that LinkedIn provides, users can access detailed information about visitors to their news and content. For example, they can find out who viewed their news, what job title the visitor has, where they come from, and what their preferences and interests are.

An example of monitoring on the LinkedIn platform is shown in the picture, where it can be clearly seen that the number of views increases significantly between March 12 and 17, because during that period the posts on this social network were intensified.

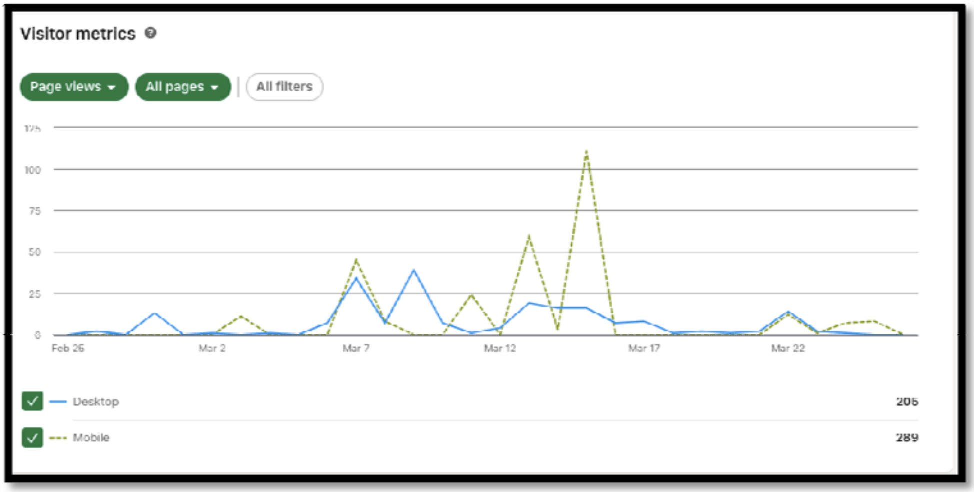

Figure 8.Follower activity by day of the month

A comparative review of the announcement in the first and last 90 days provides the possibility of analyzing the activities that contributed to a significant increase in the reach of visitors in the last days compared to the first days of the announcement, as shown in Figure 9. Out of a total of 1,700 views, 1,650 views refer to the period in the last 90 days. It is also possible to monitor the engagement of existing or new followers in Figure 10.

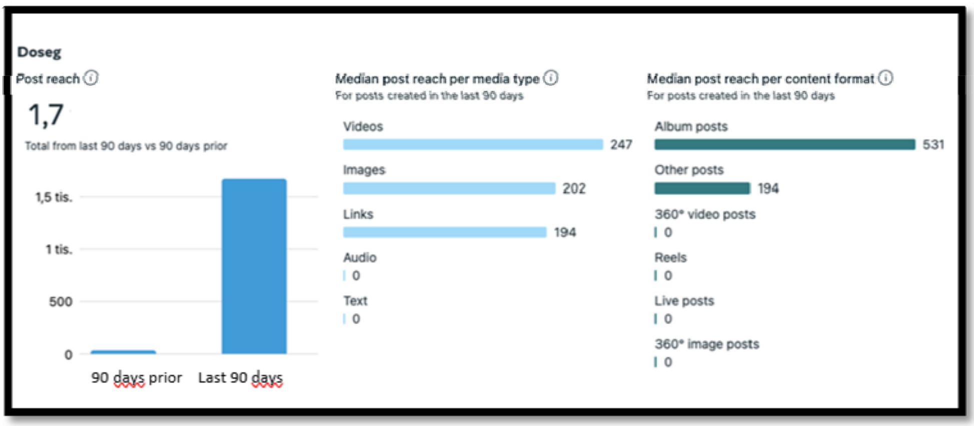

Figure 9.Follower's statistics over time

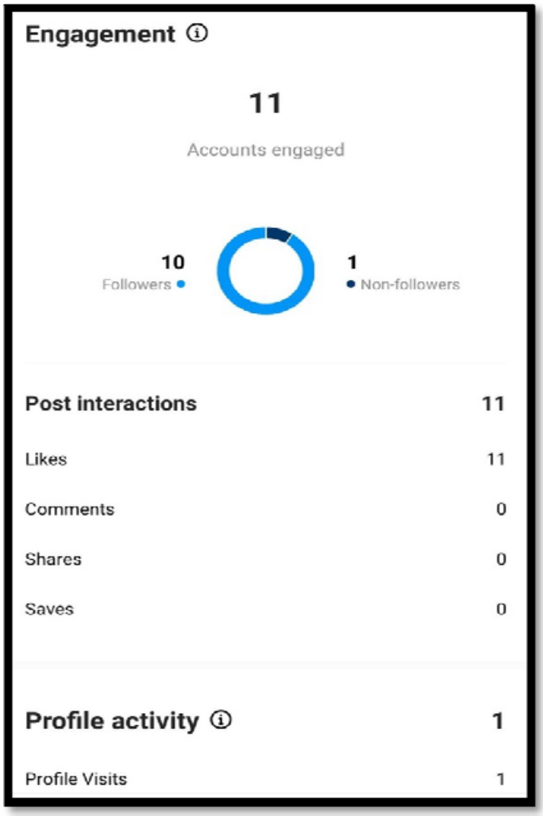

Figure 10.User engagement

Analytics in the creation of a strategy for the publication of a campaign is an important element. That is why it is necessary to study all the analytical data of previous campaignsin detail, to design a high-quality overview of the advertising campaign, target group, selection of media, and the method of monitoring and measuring the budget spent as well as the effects of the campaign.

3.3. Analysis of traditional marketing in the market of Bosnia and Herzegovina

In the previous chapter, we explained the importance and possibilities of digital marketing. However traditional marketing is still strongly represented in the FMCG industry in our region. The presence of traditional marketing in the market of Bosnia and Herzegovina is still significant, despite the rapid development of digital marketing. There are several reasons for maintaining traditional marketing methods in this region:

- Demographic factors: Bosnia and Herzegovina has a diverse demographic structure, including older generations who are not as digitally savvy and prefer traditional media such as television, radio and print media. To reach these demographic groups, companies often use traditional marketing channels.

- Geographic spread: Bosnia and Herzegovina has a scattered geographical structure with rural areas and smaller towns that may not have the same access to digital technologies as larger cities. Using traditional marketing channels, such as billboards, flyers or local media, can be an effective way to reach these areas.

- Cultural factors: Tradition and local identity are valued in Bosnia and Herzegovina. Companies often use traditional marketing methods to connect with the local community and highlight their affiliation and support for local values. For example, local event sponsorships, traditional media advertising campaigns or direct marketing can be effective ways to build trust and connections with local consumers.

- Budget constraints: Digital marketing can be more expensive compared to traditional advertising methods, especially for smaller companies with limited budgets. Using traditional marketing channels can be a more affordable and effective way to achieve visibility and engagement with your target audience, especially in smaller local markets.

Traditional marketing evolved from the original forms of advertising and refers to any type of promotion that is done using traditional advertising methods. In the market of Bosnia and Herzegovina, this means the following advertising channels:

- television and radio advertising,
- printed media (daily newspapers, magazines, etc.),
- printed materials (leaflets, brochures, catalogs, etc.),
- fairs and presentations,
- billboards and posters.

When it comes to the campaign strategy, it is important to adapt it to the client's requirements and financial capabilities. A campaign approach can include different channels and methods of promotion, depending on the goals and preferences of the client. In the case of InStore magazine, the portal announcements and the print edition often go hand in hand to achieve maximum reach and effectiveness. For clients, it is crucial to achieve a large number of views with favorable financial conditions.

According to research conducted by Altermedia company, the promotional price and free packaging have proven to be the most successful forms of promotion in the FMCG industry in 2022. These promotional tools often attract consumers and encourage their purchases. A detailed analysis of the research results can be seen in Figure 11.

Figure 11.Forms of promotion in FMCG

4. Swot Analysis of Traditional and Digital Marketers in the Market of Bosnia and Herzegovina

When analyzing the market of Bosnia and Herzegovina, confirmation of the increasing significance of digital marketing can be found in a study conducted by the Regulatory Agency for Communications (RAK). The survey results showed that at the end of 2021, there were a total of 797,893 internet subscribers in Bosnia and Herzegovina. The agency estimates that during the same period, there were 3,374,094 internet users, indicating an internet penetration rate of 95.55% in 2021. Regarding the type of internet access, there are no longer any recorded subscribers using dial-up analog and ISDN modems in the Bosnian and Herzegovinian market. The number of broadband connections is equal to the total number of internet subscribers, which amounts to 797,893 subscribers. Statistics reveal that xDSL was the dominant type of internet access in 2021, with its subscriber count representing 52.14% of the total number of internet subscribers in Bosnia and Herzegovina. Cable access ranks second, with its subscriber count making up 33.26% of the total number of internet subscribers [15].However, analyzing the user distribution across regions of the country leads to the conclusion that the potential market accessible for digital marketing is significantly less developed and less favorable for implementing certain marketing activities. This is because Bosnia and Herzegovina has many rural areas where the population lacks digital literacy.

The key differences between digital and traditional marketing are described through the SWOT analysis in Figure 12 and Figure 13. One of the differences lies in the greater and faster accessibility through online media channels compared to traditional medias such as TV, radio, or newspaper articles. In digital marketing, there are opportunities for interaction with customers, whereas traditional media is limited in that aspect. The advantages of traditional marketing are that depending on the product or target audience, it can be a more suitable form of communication for conveying the desired message.

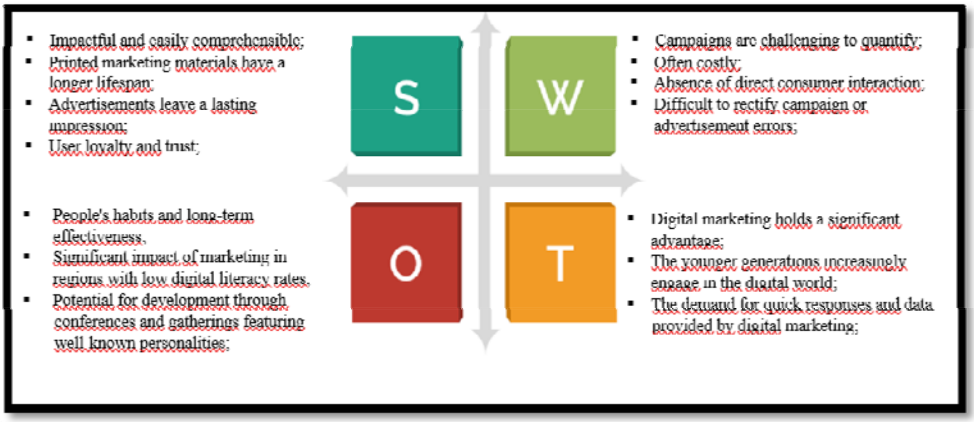

Figure 12. SWOT analysis of traditional marketing

In the past few decades, the information technology industry has experienced significant growth and development, impacting all other industries worldwide. Similarly, digital media has gained increasing importance. The emergence of COVID-19 has further contributed to the digital advancement of marketing, especially in online sales. A number of companies have changed their business methods and marketing strategies.

The most significant advantage of digital marketing is the reduced costs compared to traditional forms of promotion, allowing small and medium-sized companies to invest more easily in marketing. Advertising costs on television are often inaccessible to less developed companies, leading them to opt for digital advertising methods more frequently. Additionally, the costs of creating visual and textual content for the internet are several times lower than those for print media.

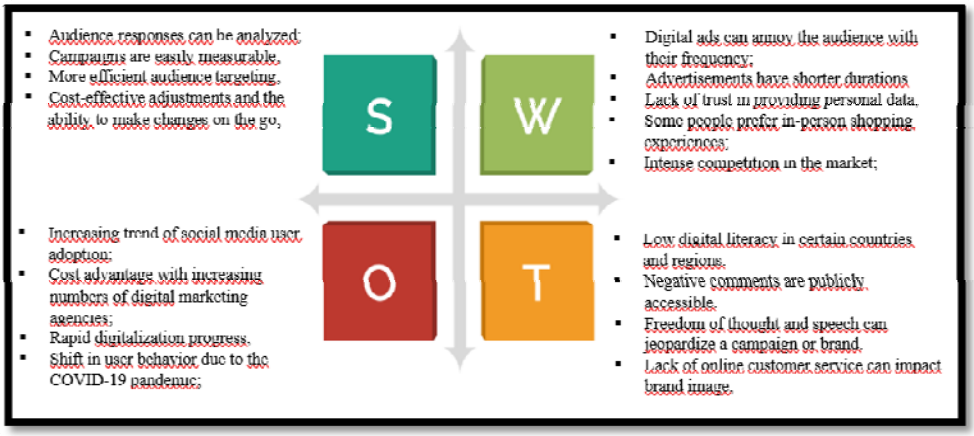

Figure 13. SWOT analysis of digital marketing

Figure 14. Digital and print edition of the magazine

As a key advantage, the conducted research highlights that digital marketing enables greater benefits and more effective management of key activities with lower investments, thanks to exceptional opportunities for thorough analysis and reporting. Figure 14 illustrates the capabilities offered by digital edition analytics compared to the print edition. We can conclude that the daily number of website visitors reaches the monthly number of readers for the print edition. An example of the estimated commercial and PR value of a one-month campaign(with carefully planned activity focused on presentation and promotion) through various communication channels is depicted in Figure 15.

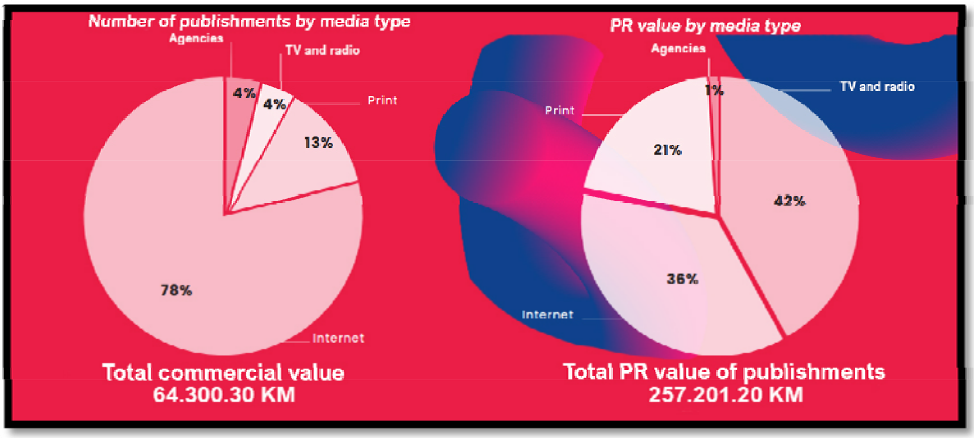

Figure 15.Commercial and PR value of publications

The commercial value does not include PR articles and influencer engagements, whereas in PR campaigns, this aspect is most prevalent. We can conclude that PR campaigns, compared to advertisement-based posts or images, require significantly higher marketing investments.

Despite the presence of digital marketing, traditional marketing continues to exert its influence in the market of Bosnia and Herzegovina, capitalizing on factors such as the widespread familiarity with conventional marketing channels and the capacity to engage a broader audience. However, traditional marketing also exhibits certain weaknesses, such as high costs and limited interaction with consumers. These weaknesses can present challenges for companies and organizations in Bosnia and Herzegovina. On the other hand, traditional marketing presents opportunities in the local market by enabling targeted campaigns towards specific geographic segments and fostering brand consolidation and consumer confidence. However, the pervasive threat to traditional marketing lies in the changing consumer habits, characterized by an escalating preference for digital media and channels.

5. Conclusion

Digital marketing is increasingly gaining prominence in today’s business environment due to its ability to effectively engage target audiences on digital platforms, its capacity for precise targeting and personalized messaging, and its enhanced measurability of results and return on investment. However, traditional marketing still holds value in specific contexts, such as localized markets and target segments that exhibit a preference for traditional media channels. A comprehensive analysis of the advantages and limitations inherent in both approaches provides valuable insights for marketing professionals operating within the market of Bosnia and Herzegovina, enabling them to make informed decisions regarding the most suitable approach based on their specific objectives, target audience, and available resources. While digital marketing continues to witness a growing significance, it is important to recognize that traditional marketing channels still maintain their relevance within the market of Bosnia and Herzegovina. Hence, a strategic integration of digital and traditional marketing strategies becomes paramount in order to formulate a comprehensive marketing strategy that ensures brand success. By effectively harnessing the strengths of both approaches, marketers can optimize the targeted reach and measurable impact afforded by digital marketing while capitalizing on the brand-building potential inherent in traditional marketing.

Based on empirical findings and a comprehensive review of relevant scholarly literature, it becomes evident that the emergence and development of digital marketing have exerted a profound influence on society, particularly among younger generations. The proliferation of social media platforms has brought about transformative societal changes, impacting both individuals and businesses, and necessitating a recalibration of their plans and strategies to effectively navigate this dynamic landscape.Overall, the study underscores the increasing importance of digital marketing while acknowledging the enduring relevance of traditional marketing in the context of the Bosnian and Herzegovinian market. It emphasizes the critical need for marketers to integrate these approaches cohesively to achieve comprehensive marketing objectives, thereby positioning their brands for sustained success in the evolving marketplace.

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The Importance of the Application of the Big Data Concept for Small and Medium-Sized Enterprises

Savo Stupar*[1], Mirha Bičo Ćar[1], Haris Arslanagić[1]

Abstract: *Business operations of companies in modern conditions are subject to enormous market, social and especially technological pressures from the environment. Information and communication technologies have become so incorporated both in our everyday life and in the operations of every company, that without them we feel almost lost and helpless. Big Data, as a theoretical (philosophical) concept has existed for decades, but only recently, thanks to the extraordinarily rapid development of information and communication technologies, it has become applicable in practice, and as a business concept it has been recognized as a unique opportunity for success in the business world. Like all organizations, small and medium-sized enterprises can find a unique opportunity to improve their own business in the application of this concept. The number of users is growing exponentially, generating a huge amount of different data every second through different sources (YouTube, Twitter, Instagram, Facebook, Google, Skype, Internet, E-mail). All those unimaginably large amounts of data need to be stored somewhere: processed, analyzed, presented and interpreted, and then propose (suggest) specific business solutions based on those results. Realization of those activities in real or reasonable time, and often unexpected and surprising conclusions, are made possible by the Big Data concept. This article aims to shed light on the concept and technology of Big Data and its application at the level of small and medium enterprises. Big Data is a theoretical and technological concept, which is able to revolutionize the way of decision-making in companies and achieve extraordinary and concrete results. A secondary, but no less important, goal of writing this paper is to point out the importance of small and medium-sized enterprises, which outnumber the large ones. Most of them strive for a stable, dominant and high market position, so it can be concluded that they are extremely important for development and progress of each country.*

Keywords*: IT-supported decision-making in real time, Big Data concept, small and medium-sized enterprises, opportunities and benefits, enterprise performance, business result.*

1. Introduction to Big Data

One of the consequences of globalization is the generation of enormous amounts of data and information that exist in the business environment. The

*[1]University of Sarajevo, School of Economics and Business, 71000 Sarajevo, Bosnia and Herzegovina
E-mail:savo.stupar@efsa.unsa.ba

challengefacing all modern, and especially small and medium enterprises (SMEs), is to use as much data as possible, store it, separate the necessary from the unnecessary through filtering, and finally process the most important ones. The ultimate strategic goal arising from the aforementioned challenge is profit maximization, improvement of market, external and internal performance, strengthening of market position and long-term, profitable business. In order for as many data as possible to participate in the process of their transformation into information and knowledge, it is necessary to manage that data in the right way, that is, to overcome the difficulties that appear during their management. Managing data in enterprises is difficult for many reasons [1].

Firstly, the amount of data grows exponentially over time. A lot of historical data has to be stored for a long time, and new data arrives quickly. For example, to be able to serve the 40 million people who like to play ‘’fantasy football’’ (American Football League), websites such as ESPN.com, NFL.com and CBSSportLine.com must manage petabytes of sports data. A petabyte is about 1,000 terabytes or a trillion bytes or more precisely 1024 terabytes. An exabyte is about 1,000 petabytes or more precisely 1024 petabytes. Another example arelarge retailers such as Walmart stores which need to manage exabytes of data to support millions of customers. In addition, data is also scattered across different organizations and collected by many individuals, using different methods and devices. These data are often stored on numerous servers and locations and in different computer systems, databases, formats, and different human and computer languages.

Another problem is that data is generated from multiple sources [1]: internal sources (e.g., corporate databases and company documents), personal sources (e.g., personal intentions, opinions and experiences) and external sources (e.g., commercial databases, government reports, and corporate websites). Data is also generated from the Internet (from the Web) in the form of customer data. Click-through data is the data that visitors and customers produce when they visit a website and click on hyperlinks. That data leaves a trace of user activity on the Website, including user behavior and browsing patterns.

In addition to the above problems, other problems are created by the constant growth of data from new data sources, such as blogs, podcasts, videocasts, and radio frequency (RFID) identifier tags as well as other wireless sensors. Most of this data is unstructured, which means that its content cannot be reliably recorded in a computer archive. Examples of unstructured data are digital images and video recordings, audio recordings and musical notes in MP3 or MP4 format files. In addition, data becomes outdated over time. For example, customers move to new addresses or change other master data, companies abandon contracted work or procurement, new products are developed, workers are hired and fired, and companies expand operations to new countries. Data is also subject to destruction. Physical destruction of data refers primarily to problems related to the media on which the data is stored. Over time, temperature differences, humidity, and light exposure can lead to physical problems with storage media that make it difficult or impossible to access data. Another aspect of data destruction is the inability to access data, due to malfunctions in the devices used to access the data or the inability to acquire an outdated device. For example, today it is almost impossible to find a 5.25-inch or 3.5-inch drive for writing and reading data from floppy disks. As a consequence, 5.25-inch or 3.5-inch diskettes have become relatively worthless, except in the case when the company owns a functional drive (device drive) or has converted data from diskettes to modern media such as CDs or DVDs. Security, quality and integrity of data are critical activities in every company, which should be taken care of, because they can be compromised very easily. In addition, legal regulations relating to data vary between countries, as well as between industries, and they change frequently.

The third problem derives from the fact that, over time, companies have developed information systems for specific business processes, such as transaction processing, supply chain management, and customer relationship management. Specific information systems supporting these processes impose unique requirements in relation to data, which can result in repetition and contradictions in data within the company. For example, the marketing function may maintain information about customers, sales territories, and markets. This data may be duplicated with data within the billing function of products or customer services. This situation can lead to non-compliant or inconsistent data within the company. Such data can prevent a company from developing a unified view of a potential problem to be solved [1].

Such problems make data difficult to manage. In response, companies are using databases and data warehouses to manage their data more efficiently. Therefore, it is necessary to analyze the life cycle of data, which should show how companies process data and manage it so that the managers can make decisions, create knowledge and use that knowledge for different purposes.

Business is based on data that has been transformed into information and knowledge. Managers apply that knowledge to business problems and opportunities. Companies transform data into knowledge and solutions in several ways. The general transformation process is shown on Figure 1. [1].

The process begins by collecting data from various sources and storing the data in a database (or databases). Data is then selected from the company's databases and processed to fit into a format suitable for the company's central data warehouse or local data warehouse. Users then access the data in the company's central data warehouse or local data warehouse for analysis.

Analysis is performed using analysis tools that search for patterns of data behavior, as well as using intelligent systems that support data interpretation.

These activities ultimately create knowledge that can be used in the decision-making process. Data (during the process itself) and knowledge (generated at the end of the process) must be presented to the users. Data presentation is done using visualization tools. The knowledge that is created can also be stored in the company's knowledge base and then used together with decision support tools to find solutions to organizational problems.

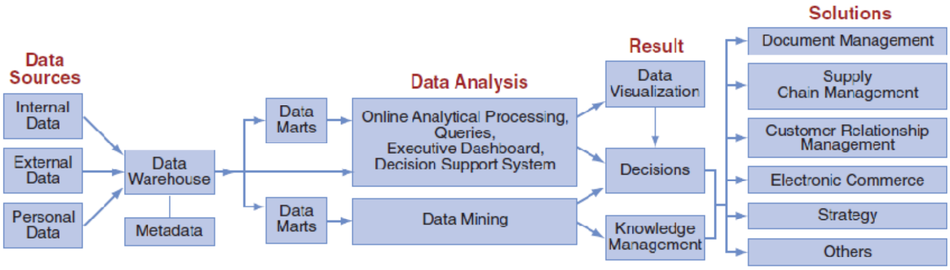

Figure 1. Data life cycle[1]

Authors Judith Hurwitz, Alan Nugent, Dr. Fern Halper and Marcia Kaufmantermin [2], believe that Big Data is not represented as a single technology, but something that includes both old and new technologies that, when used in combination, give companies the ability to manage large amounts of data from different sources, at the appropriate speed, and in the appropriate time frame. By Big Data, they mean the combination of many different hardware-software solutions, which are used for data management. Thomas H. Davenport [3] considers the concept of Big Data as a revolutionary opportunity with transformational potential for every business, but he characterizes the name itself as problematic. As a results of the imprecise term of this concept, he suggests to companies its decomposition, in order tosimplify the strategy, and based on that, determine what are the possibilities and goals of using data. Bernard Marr, [4] a Big Data expert, states that the name of the concept is misleading because the focus is not on big data, that is, large amounts of data, but on the possibilities of their exploitation and conversion into value. By combining traditional structured data with ''messy'', companies use Big Data tools to create richer insights and make smarter decisions. Data generation today looks like a rolling snowball, according to forecaster William Higham [4]. He predicts that effective ways of using data will be more complicated at first, but will eventually become a daily part of both the business life of companies and private lives. Businesses will use Big Data technologies in an increasing proportion, and small and medium-sized enterprises must react quickly with the development of a strategy and its implementation, because a passive approach most often means disappearing from the market. Many companies are testing different approaches to data collection in order to uncover hidden patterns of business significance. All data that is an integral part of the Big Data concept can be classified into three groups: structured, semi-structured and unstructured data.

Thomas H. Davenport [3] defines structured data types as clearly defined types that are easy to find using known, specific patterns. Unstructured data represents ‘’everything else’’, i.e., data that cannot be easily found and searched because they do not have a defined pattern and are not organized in advance. Semi-structured data does not have a corresponding structure with which we associate it - e-mail, word documents and diary documents. There are many reasons why small and medium-sized enterprises fail to cope with environmental pressure and follow trends. The traditional approach in business is no longer sufficient, and the benefit of historical data is a problem due to the rapid aging of data, which further leads to wrong decisions, and in the long term to loss of market competitiveness and exit or disappearance. Resistance to the introduction of the Big Data concept was previously caused by the high cost of implementing Big Data technology in companies, but today, thanks to cloud technology, data centers and analysis tools, the application of this concept has become economically acceptable and necessary for successful business. For most countries, the number of small and medium-sized enterprises constitutes the majority percentage in the structure of the state economy, and the successfully implemented Big Data concept means a key step in the growth and life of small and medium-sized enterprises. The value of SMEs is important regardless of the economic strength and position of the country, because they contribute to economic growth, job creation and social progress. The biggest challenges faced by small and medium-sized companies are inadequate financing, poor company management, lack of training and education, but also focusing on operational business activities instead of research and investment in new technologies that will improve operations. As a result of such practices, many of them cannot keep up with technological changes and innovations. The report of the European Commission *Skills for SMEs - Supporting specialized skills development: Big Data, IoT and Cybersecurity for SMEs*[5], states that many companies understand the benefits of data-driven decision making and invest in Big Data technologies and services. Worrying data shows that very few companies embrace digitization: in 2015, only one in five European companies showed a high or very high degree of digital intensity, while only 6% showed a strategic and intensive use of data. According to data from 2018, only 12% of European SMEs used forms of Big Data, compared to 33% of large enterprises. The result of the research shows that even 90% of small and medium-sized companies believe that they lag behind digital innovations [6].Although this concept was neglected and ignored by small and medium-sized companies until recently, the approach is starting to change significantly, and the goals of strategic planning and implementation of Big Data strategy are being created. We find benefits in sales improvements, personalized user experience, arrival of new clients, control of production and distribution processes, reaction and reduction of error chances, but also active market analysis. Big Data is not intended only for large companies with large budgets at their disposal, but on the contrary, today this concept has more potential for small and medium-sized companies.

2. Defining the term Big Data

The problem of defining the term Big Data was most simply explained by the Israeli professor of Psychology and Behavioral Economics, Dan Ariely, with the following statement from 2013 [7]:
''Big Data is like teenage sex: everyone's talking about it, no one really knows how to do it, everyone thinks everyone else is doing it, so everyone says they're doing it too...''
Big Data is a term that has infiltrated our everyday world - from commercial applications to research in various fields such as psychology, geography, humanities or healthcare. Considering how often we encounter this term, it is extremely important to try to find an answer to the question: what exactly is meant and what does Big Data refer to? The name itself did not appear recently, and is not a novelty. It was probably used for the first time in the mid-90s at one of the meetings at Silicon Graphics (a company for the production of high-tech computer hardware and software solutions).
The first appearance in academic literature dates back to the early 2000s, in the field of statistics and econometrics, where Big Data is used to describe the explosion in the quantity and quality of available and potentially significant data, as a result of unprecedented progress in data creation methods and data storage technologies. [8]

The European Commission defines Big Data as [9]:
''Large amounts of different types of data generated from different sources such as people, machines or sensors. This data includes climate information, satellite images, digital images and videos, and GPS signals. Big Data can also be linked to personal data, i.e., any information linked to an individual, ranging from names, photos and e-mail addresses, bank details, posts on social networks, websites, medical data or computer IP addresses''.
Similar to the European definition, in the United States, the National Science Foundation (NSF) views Big Data as [10]:*''Various, diverse, complex, longitudinal and distributed data sets generated from various instruments, sensors, internet transactions, e-mails, videos, and all other digital resources available both today and in the future''.*
Despite the fact that most of these definitions are based on the same or similar elements, the term Big Data remains conceptually incomplete due to the

different ways in which it is used in different contexts. In order to solve this problem, experts are trying to propose a standard, that is, a commonly defined definition of Big Data. De Mauro and other authors [11] propose a consensual formal definition in which:
''Big Data represents an information asset characterized by high volume, speed and diversity, which requires specific technology and analytical methods to transform it into value''. Other experts like Floridi criticize traditional attributive definitions because they still remain vague and insufficiently precise, and do not clarify on the real way, what exactly does Big Data mean.

The problem is also in the part of the term ''Big'', because with the exponential growth of computer capacities, it is impossible to define a threshold for big data because they are relative and differ by factors such as time and type of data.

Despite all efforts to bring the debate on the definition of Big Data to an end, regardless of the various definitions set so far, a consensus on an adequate definition of Big Data has not yet been reached. The problem of using digital data sets, which on the one hand can have a significant benefit for research, but on the other hand, reveal sensitive data about research participants, is particularly highlighted. Another loophole in the law is the use of data from digital platforms (most often social networks), without the exclusive consent or awareness of the user. A scandal like Cambridge Analytica related to the presidential elections in the USA in 2016 drew attention to the weak regulation of research practices. Public outrage and pressure resulted in the planning and creation of strategies to protect private users.

According to a survey conducted among 39 Swiss and American researchers, the basic and practical definitions of Big Data were singled out (Table 1. and Table 2.) [8].

Table 1. Basic definition of Big Data based on attributes(Source: [8])

1. Essential Definition based on attributes/properties	
1.1 Several V s definition	Definition based on the traditional attributes of Big Data (4 Vs)
1.2 Volume	Vast amounts of data
1.3 Variety	Heterogeneous data, both structured and unstructured
1.4 Complexity	Very complex data compared to data that is traditionally collected
1.5 Impact	Data that has a huge impact and value for society

Basic definitions are based on attributes or properties. This would mean that Big Data is defined according to one or all of the ''V'' characteristics. The dimensions listed here are used to illustrate the numerous technical challenges brought about by Big Data technologies. The problem with this form of definition is the establishment of the number of attributes, or the selection of the primary, most frequently selected one - quantity (volume), which is mostly mentioned in the sense of a large number of samples. Other respondents mention the diversity and complexity of data as well as more important attributes.

Table 2. Practical definitionsof Big Data (Source: [8])

2. Practical Definitions	
2.1. Source of Data	Data that comes from digital technologies
2.1.1 The Human Component	Data that is generated from people
2.3. Collection	Data collected with no purpose or with no informed consent
2.4 Data Processing	Data that needs sophisticated computational processes to be analyzed
2.5 Problem Solving Tool	Method that is capable of answering questions

Practical definitions, instead of being based on characteristics, are based on practical processes such as data collection and data processing as important components of the Big Data definition. Thus, practical definitions pay attention to the data source, even the human component of generation. These factors have created the opinion that Big Data does not imitate the real picture of the world, but that it even gives an incomplete and inaccurate representation of reality. Another key factor is data collection, especially in cases where there is no purpose. The typology of procedures in data analysis also enters as a defining factor, because the data belonging to Big Data are demanding and therefore require specific algorithmic and computer processes. Finally, one of the key components is a tool for solving problems, which is reflected in Big Data as a pragmatic ability to act as a tool for answering questions and finding timely solutions. Due to the lack of conceptual clarity, certain researchers did not even use the term Big Data, considering it a popular phrase, which is a cultural product of our living world, and not a separate entity in material form, and therefore can only create confusion. According to Timo Elliott, Table 3 shows seven types of definition creation, based on more than 33 Big Data definitions. Each of the definitions tries to describe a certain problem from one aspect. A comprehensive definition can become very complex and long.

Table 3. 7 most popular Big Data definitions(Source: [12, p. 10.])

No	Type	Description
1	The original big data (3Vs)	The original type of definition is referred to Douglas Laney's volume, velocity, and variety, or 3Vs. It has been widely cited since 2001. Many have tried to extend the number of Vs, such as 4Vs, 5Vs, 6Vs … up to 11Vs
2	Big Data as technology	This type of definition is oriented by new technology development, such as MapReduce, bulk synchronous parallel (BSP — Hama), resilient distributed datasets (RDD, Spark), and Lambda architecture (Flink)
3	Big Data as application	This kind of definition emphasizes different applications based on different types of big data. Barry Devlin [37] defined it as application of process-mediated data, human-sourced information, and machine-generated data. Shaun Connolly [38] focused on analyzing transactions, interactions, and observation of data. It looks for hindsight of data
4	Big Data as signals	This is another type of application-oriented definition, but it focuses on timing rather than the type of data. It looks for a foresight of data or new "signal" pattern in dataset
5	Big Data as opportunity	Matt Aslett [39]: "Big data as analyzing data that was previously ignored because of technology limitations." It highlights many potential opportunities by revisiting the collected or archived datasets when new technologies are variable
6	Big Data as metaphor	It defines Big Data as a human thinking process [40]. It elevates BDA to the new level, which means BDS is not a type of analytic tool rather it is an extension of human brain
7	Big Data as new term for old stuff	This definition simply means the new bottle (relabel the new term "big data") for old wine (BI, data mining, or other traditional data analytic activities). It is one of the most cynical ways to define big data

The right solution in defining is the use of rational reconstruction where it is necessary to determine the reasons behind practices, decisions and processes and make them easier to understand.[12, p. 10.]

The purpose of Big Data is to gain insight into the past – metadata patterns from historical data, deep understanding of problems and predicting the near future in a cost-effective way. However, these important and indispensable attributes are often omitted in many definitions that focus only on one problem or one aspect.

Bernard Marr, the world's leading expert on Big Data, also states that the name Big Data is simplistic and misleading. Marr shifts the focus from the amount of data to the human ability to work with that amount and create value. He also predicts that the term Big Data will disappear over time, and that the successor will be SMART Data, precisely because it is not the amount of data that brings fundamental changes, but the ability to analyze and convert different data into value, even with smaller and smaller need for supercomputers. He says the following about Big Data[4, p. 9.]
''The basic idea behind the phrase Big Data is that everything we do leaves a digital trail (or data) that we (and others) can use and analyze to become smarter. The driving force in the world is access to ever-increasing amounts of data and our ever-increasing technological ability to mine that data for commercial purposes''.

Thomas H. Davenport, [3, p. 1.] a professor and lecturer at MIT and Babson College, believes that Big Data is a misnomer and that it is just a catchy name for data that does not fit the usual framework. Davenport believes that attention is focused on the size of the data and the word ‘’Big’’, while in fact it should be focused on the shortage and lack of data structure. He also emphasizes that organizations can benefit from this modern term if it creates energy and enthusiasm. Together with other experts, he predicts a short lifespan of this term, and concludes that the term is accepted by the media and start-up companies, but that it is reluctantly accepted by technologically oriented companies. However, if we want to explain the wide range of new and massive types of data that started in the last decade, there is no better term for it than Big Data. Davenport explains [3, p. 1.]: *‘’Big Data represents data that is too large or too numerous to be stored on a single server, too unstructured to be represented in a row-column view of files, or they change too frequently to be retained in a standard data warehouse’’.*

Authors Judith Hurwitz, Alan Nugent, Ph.D. Fern Halper and Marcia Kaufman [2, p. 1.] consider Big Data to be a different combination of hardware and software solutions, i.e., numerous technologies for data management that enable companies to store, manage and manage huge amounts of data at the appropriate speed and in the right time to obtain the necessary benefits [2, p. 1.].

From the previous considerations, we can conclude that the very name of the term, which we are investigating, causes numerous polemics, discussions and many problems. However, although there are a large number of definitions, Big Data still does not have a simple, logical and understandable explanation. The use of the term causes discomfort and uncertainty when using the term because it is partially seen as a cultural phenomenon that includes the development of computer technologies, instead of a clearly defined entity or methodology. In order to correctly understand the essence of the concept of Big Data, it is necessary to decompose the concept into its various constituent parts, which would avoid generality and reach specific qualities. Until then, it is definitely necessary to put efforts in researching the conceptual definition of Big Data, that is, clearly defining and deciding what it is and what it is not.

3. Data attributes, which are part of the Big Data concept

Basic attributes, or data dimensions, that distinguish ''ordinary'' data from data that is the subject of the Big Data concept:[13]

- **Volume** – large amount of data that is generated, collected, stored, processed and shared for analysis. Today, this amount is measured in terabytes, petabytes, exabytes and increasingly zettabytes. As an example of this attribute, we can take all transactions with credit cards in one day, in the territory of Europe.

- **Velocity** – the speed at which new data arrives is enormous and is higher than the speed of data processing, because it is about the permanent generation of a large amount of data in real time. For example, creating social media posts within an hour or a day.
- **Variety** – data is available in different formats and comes from different sources, and is mostly unstructured. This attribute refers to the variety of incompatible and inconsistent data formats and structures. An example of different formats can be audio and video recordings that we receive from surveillance cameras from different locations in a city.
- **Value** – as the 4th characteristic, it starts from the assumption that the data in itself has a certain potential value, i.e., the value extracted from all the data.

Later on, some authors [14, 15] added some new attributes, which start with the letter ''V'' like the attribute ''Vision'' (new ideas with old data), then ''Verification'' (the possibility of checking whether the data meets a certain set of specifications, with this process taking place before the data is subjected to any analysis), ''Validation'' (checking whether the purpose of the data is satisfied and consistent, i.e., whether the same accurate and appropriate conclusions can be obtained from the same set of data regardless of the number of repetitions of the analysis, with the fact that this process takes place after the data have been subjected to analysis) or ''Variability'' and ''Reliability'', which have not yet spread.

When defining the characteristics of data, which are the basis of the Big Data concept, a large number of data scientists from practice, as well as theorists, do not consider that only these 4 characteristics are sufficient to distinguish them from ''standard'' data. At the same time, they try to ensure that each of the additional features begins with the letter ''V'' [16].In this way, from the original characteristics of the data, which were marked with ''3V'' it became ''4V'', then ''10V'' and finally to ''42V'' [17].

4. Data sources that are the subject of the Big Data concept

Data is the driving force for the information society, without which the innovations on which modern man depends would be almost impossible. The data that is an integral part of the Big Data concept is at the center of modern science and business. The importance of that data is perhaps best illustrated by the fact that in 2013 the English government allocated 189 million pounds for research in the field of Big Data. Synthetic biology, as the next discipline in terms of the amount of money allocated, received 88 million pounds. Big Data sources include fingerprint databases, DNA databases, airline flight records, educational institution records, credit card transactions, Facebook pages, e-mails, public health records, etc.[16].

In the era of **BIG DATA**, the value of data lies in the sum of all its possible applications, and these values can be released in several ways [14]:

- **New use of ''old'' data**
  Since 2012, a group of companies (*IBM, Honda, Pacific Gas* and *ElectricCompany* of California) has been requesting data on the deployment of electric charging stations for electric cars. Their goal was to find out when and where electric cars could run out of power. They conducted the research on the basis of data such as: the charge level of the car battery, the position of the car, the time of day, the number of available charging points at the nearest electric charging stations, etc. To that data, they also added electricity consumption from the electrical network and archival (historical) records of electricity consumption models. Based on the data thus collected, IBM was able to build a model of optimal places for the construction of electrical stations. After the construction of the station, it will be possible to add data about the current weather, weather forecast, and the difference in prices in nearby electric stations to the model. They used primary information from data such as a battery level indicator that tells the driver when it's time to charge and data on energy usage, which is collected by the electrical grid to keep it stable. Then, from the same data, they calculated secondary information such as determining the time and place for recharging the battery, that is, determining the most suitable places for the construction of electrical stations. They added the additional use of information from GPS data on the car's position and historical data on the monitoring of energy consumption in the network to their calculations.
- **By merging, that is, by crossing different sets of data**
  Although many data are valuable in themselves, when cross-referenced with other databases their value can increase even more. Aggregation

orintegration of data can provide completely new insights into the field, enable some new uses, or provide data for some new innovations.

- **Extensible/multiple data use**
  If the data is not used only for the primary, i.e., the first purpose for which it was collected, but also finds some new application, then we can say that it is a multi-purpose use of data. Sometimes a new purpose is ''discovered'' only after the data has been collected, but that does not diminish its power.
- **Using data ''exhaust gases'' and opening ''tombs'' of data**
  ''Exhaust gases'' of data is a term that refers to those data that are created as a side product (by-product) of user interactions on the network, such aswhere users clicked, how long they stayed on the website, what they typed, and which companies can use to improveexisting services or offer new ones.
- **By opening the ''tombs'' of data**
  Another place that can serve us as a source of Big Data is ''tombs'' of data. It is a place where collected data is kept that was (perhaps) once used and then archived without further use. It is clear that not all data sources for Big Data will be successful, nor will all their applications. Research shows that even ¾ of hospital information systems in America were unsuccessful. In Great Britain, they rejected the investment of 17 billion dollars that was invested in the Big Data information system of the *UK National Health Service* center. In America, they stopped a $350 million project known as the Cancer Biomedical Informatics Grid that was supposed to develop standards for tagging and sharing biomedical data and data processing tools.[14]

Large data sets come from a variety of sources[16]:

1) **Social networks:** the growth of social networks such as e.g., YouTube, Instagram, Twitter, Facebook influence the exponential growth of the total amount of data.
2) **State government data:** state governments generate and collect large amounts of data, related to the total population, health care of the population, as well as various types of forecasts. These types of data are inevitable for Big Data analysis and research.
3) **Peer to Peer communication:**with the development of technology, the amount of data generated in this way also increases. These are e-mail messages, SMS messages, phone calls from mobile phones, various types of chats, etc.
4) **Media:** Various websites, portals, magazines, images, videos, blogs, podcasts, etc., all belong to the Big Data system.

5) **Customer interaction:** Almost all successful companies start building their customer databases, using websites, which are accessed by customers. The most common sources of data come from user data. For example, actions such as downloading, registering and filling out an account from a website. Companies are starting to collect that customer data, classify different types of customers and come up with strategies to do business with different types of customers.
6) **Other sources:**stated in Figure 2.

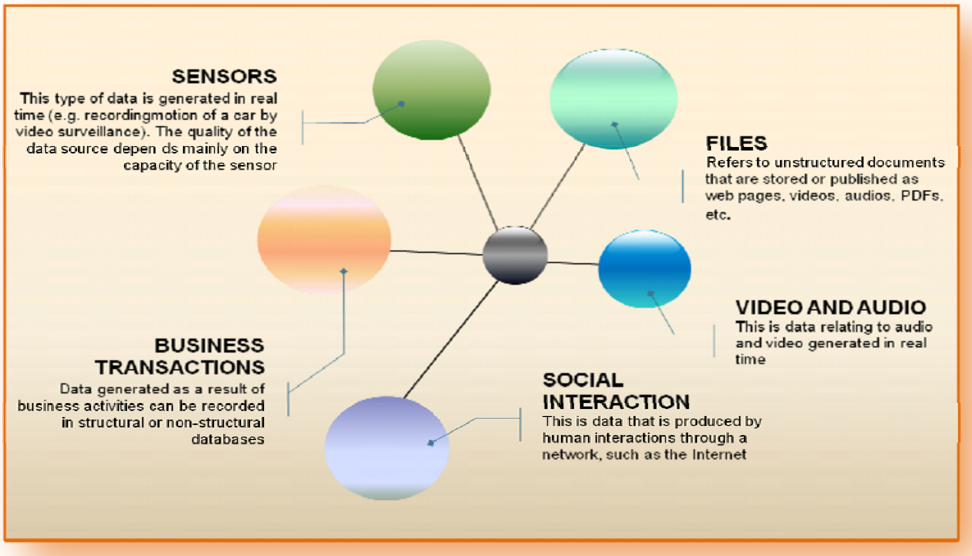

Figure 2: Additional data sources for Big Data
(Source: [16])

5. Research and analysis of the application of the Big Data concept in SMEs

The aim of this paper was to check the impact of the Big Data concept on the operations of small and medium-sized enterprises, that is, to try to answer the questions: whether the application of this concept has direct and positive effects on small and medium-sized enterprises, whether the managers of these enterprises are generally familiar with this concept and the importance it carries, and whether the application of the Big Data concept affects the operation and business processes of small and medium-sized enterprises to be as simple and fast as possible. Every company expects to achieve market competitiveness and market survival in the long run. Nevertheless, small and medium-sized enterprises have many concerns when it comes to market changes and changes in the way of doing business, which primarily refers to the use of Big Data in everyday business. Big Data is a very young research area when viewed through the theoretical and practical prism of application in small and medium-sized enterprises. By researching the relevant literature, one can come to the conclusion that the first relevant research on Big Data was not published until 2011. Even most of the research that has been done on this topic does not follow organizations of a specific size such as small and medium-sized enterprises, and yet most research shows that small and medium-sized enterprises approach Big Data activities with a degree of reluctance compared to large companies. The most common reason for this is insufficient knowledge of the Big Data concept. Although we have more and more information about Big Data technology over time, research on small and medium-sized enterprises is still at an early stage, and this is not an area that is interesting for many researchers. Small and medium-sized enterprises do not receive significant funds for research, and it is possible to argue that in most cases, they do not even accept them at all. This is why small and medium-sized enterprises are a relatively unexplored and unknown field, especially when it comes to the effects of the Big Data concept in their daily operations. Their positions are often limited and artificial. Of course, much more developed countries conduct more research on this topic. This research should provide insight into the attitude of small and medium-sized enterprises towards the application of the Big Data concept in their operations. However, we cannot say that small and medium enterprises are unimportant and just ignore their importance. On the contrary, small and medium-sized enterprises play a major role in the economic stability and total national income of each country.

The adoption of Big Data technology enables companies to create a clear picture of their users and their requirements with the aim of making the best possible decisions, based on facts and information, for setting appropriate marketing strategies. Managers of small and medium-sized enterprises, in turn, expect timely and high-quality market analysis and prediction of user behavior from Big Data technologies. The application of Big Data technology in small and medium-sized enterprises can lead to increased flexibility, efficiency and effectiveness, better and more adequate reactions and the possibility to meet the expectations of users, and thus to realize their competitive advantage.

The adoption and application of the Big Data concept in small and medium-sized enterprises depends on technological, organizational, managerial and environmental factors, as well as other factors that affect the company's operations.

5.1. Research Methodology

The research technique used in this paper is Desk research or the technique of secondary research, which implies the collection of existing data from existing and valid sources. Secondary data includes literature, i.e., books, magazines or scientific articles in printed and online editions, as well as relevant and confidential websites. Desk research consists of the following steps: defining research questions and topics, identifying sources, i.e., creating a list of potentially useful internal or external sources, conducting research, evaluating reliability and ranking potential sources, and finally, creating a summary, which can be a formal report or a visual a map. Due to the complicated system of identification, selection and contact with small and medium-sized enterprises in the territory of Bosnia and Herzegovina, it was not possible to carry out the planned survey. The lack of legal regulations for small and medium-sized enterprises also contributes to this, as well as the different procedures and laws that apply to small and medium-sized enterprises in certain parts of Bosnia and Herzegovina: the Federation of Bosnia and Herzegovina, the Brčko District and the Republic of Srpska. Unfortunately, on the territory of Bosnia and Herzegovina, there is no unified approach and view of small and medium-sized enterprises. Because the primary research was not possible, the best alternative is the desk research methodology. In this way, we can present the bigger picture, look at the details of importance, break down the research into elements and review many more examples for the proposed hypotheses. In addition, with this approach, we can find out what the situation is in other countries and how small and medium-sized enterprises differ or how they are similar to each other depending on the geographical location.

5.2. Research results

Research carried out in Iran in 2020, named *The Impact of Big Data Adoption on SMEs Performance*,[18](Narsollahi, Ramezani, & Sadraei, 2021), aims to test 20 hypotheses. This research begins with the introduction and definition of various factors. These factors are listed in Table 4. The items of evaluation and validation of components on which Big Data has an influence and vice versa, were extracted from various studies that were carried out earlier. All factors are rated on a Likert scale with numbers from 1 to 7, where 1 - I completely disagree and 7 – I completely agree. This survey was conducted on SMEs based in Iran, and the respondents of this study are top managers and middle managers working in SMEs in Iran, who responded to the survey via e-mail. A total of 2863 messages were sent in March 2020, and 836 responses were received, of which 612 were rejected due to incompleteness. The final number was 224 completed questionnaires.

Table 4. Description of influential factors in small and medium enterprises
(Source: [18])

Construct	Definition
Feature factors (FEF)	Including: Trainability, Perceived simplicity, Observability, Complexity, and Data quality and integration.
Organizational factors (ORF)	Including: Organizational data environment, Business strategy orientation, Firm size, and Industry type.
Utility factors (UTF)	Including: Perceived compatibility, Appropriateness, Perceived benefits (advantage), Relative advantage, and Perceived usefulness.
Technological factors (TEF)	Including: Technology readiness/ technology resources, Wireless technology, Availability of big data tools, Internal versus external technologies, IS competence/IT structure (infrastructure), Technological capability, and Network challenges.
Stakeholders factors (STF)	Including: Vendor support, Competitive (Perceived industrial) pressure, Government support, laws and policy, Trading partner adoption/ readiness, and IS fashion.
Financial factors (FIF)	Including: Perceived financial readiness, Perceived cost, and Cost of adoption.
Processing factors (PRF)	Including: system integration, Security and privacy, Data control, Predictive analytics accuracy, and Interpret unstructured data.
Cultural factors (CUF)	Including: Organizational (learning) culture, information security culture, and Decision-making culture.
Wisdom factors (WIF)	Including: IT expertise, Knowledge about big data, and big data awareness.
Environmental factors (ENF)	Including: Supply chain connectivity, Risks of outsourcing, Market turbulence, and Marketing and inventory.
Managerial factors (MAF)	Including: Leaders' attitude towards change, Management support for big data, Change efficacy, and Willingness to change.
Skills factors (SKF)	Including: Human resources, Staffing, and Training.
Economic performance (ECP)	Economic performance reflects the firm's ability to reduce costs associated with purchasing materials, energy consumption, waste management, environmental fines, etc. (Green Jr, Zelbst, Bhadauria, & Meacham, 2012).
Operational performance (OPP)	Operational performance (OPP) is related to the firm's capability to increase product distribution efficiency to customers (Zhu, Sarkis, & Lai, 2008).
Social performance (SOP)	Social performance (SP) reflects the status of organizational beliefs about social responsibilities, social accountability methods, policies, plans, and the evident outcomes associated with the organization's social relationships (Younis, Sundarakani, & Vel, 2016).
Organizational performance (ORP)	Financial and marketing and performance of the organization compared to the industry average (Green, & Inman, 2005).

Based on previous knowledge and their results, 20 hypotheses were developed. Hypotheses H1-H5 and H7-H12 refer to various organizational factors that are claimed to have a positive and direct impact on the implementation of Big Data technologies in small and medium-sized enterprises(Feature, Organizational, Utility, Technological, Stakeholder, Processing, Cultural, Wisdom, Environmental, Managerial and Skill Factors). Hypothesis H6 claims that *''Financial factors have a negative and reverse impact on BDA (BDA - Big Data Analytics)''* [18].Hypotheses H13-H15 claim that ''BDA *has a positive and direct impact on operational performance; environmental performance*; *social performance''*[18]. Hypotheses H16-H18 claim that *''Environmental performance has a positive and direct impact on operational performance; social performance; organizational performance''* [18], and H19 and H20 refer to *''positive and direct impact on organizational performance*'' of ''*Operational performance and social performance''* [18]

The research model confirmed almost all hypotheses, and only two were rejected (''H15: *BDA has a positive and direct impact on social performance*, and H17: *BDA has a positive and direct impact on social performance''*. [18]) Research has proven that organizational, technological, financial, cultural, managerial, environmental and stakeholder factors as well as process and skill factors have a positive and direct impact on the implementation of Big Data technology in small and medium-sized enterprises. Hypotheses 13 and 14 read: The implementation of Big Data has a positive and direct impact on the operational performance of the company and the implementation of Big Data has a positive and direct impact on the performance in the environment [18], and they have been confirmed and proven.

This research provides valuable results by determining the impact of the use of the Big Data concept by small and medium-sized enterprises on their organizational and business performance. Economic performance has a direct impact on the operational and organizational part, but what cannot be proven is the impact on the social factor of the organization. Finally, social and operational factors have a positive and direct influence on the organizational factor, and the results point to the improvement of various organizational units such as operational performance, which is reflected in the increased ability of the firm to increase the efficiency of product distribution to its users, and to increase the social performance that manifest in organizational beliefs about social responsibility, policies, plans and results. And finally, the most important fact is that the use of Big Data has a positive and direct impact on organizational performance, such as the financial and marketing effect of the organization compared to industry competitors.

This study also highlights the importance of understanding the potential that Big Data brings for better decision-making and performance improvement because by using Big Data, many strategic and profitable opportunities are created for small and medium-sized enterprises through which they can succeed in a business ecosystem where competitiveness and innovation are key drivers. Big Data is a new opportunity for SMEs to use new types of data to improve organizational agility and solve complex problems and achieve better results and performance. As a result of the application of the Big Data concept, fundamental changes are taking place in organizational operations and business performance, and consequently, organizations are moving towards a more accurate and better-informed decision-making and planning system. In the end, it can be concluded that the application of the Big Data concept represents a crucial resource for small and medium-sized companies that want to create new values, new knowledge, new processes and new products. The results of this research give managers a practical framework for deciding whether the introduction of the Big Data concept is necessary or not.

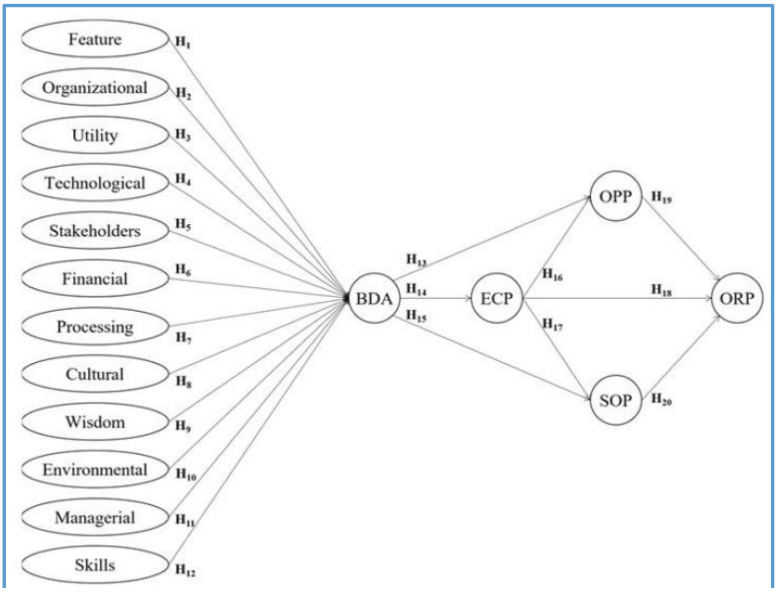

Figure 3. Cause and effect relationship of Big Data implementation
(Source: [18])

Big Data adoption in SMMEs research from 2015. [19], came to the result that small and medium-sized companies that successfully implemented Big Data strategy and analytics, achieved this precisely thanks to the influence of owners, top management, employees, that is, the general organizational culture of the company. Although a culture of case-based and evidence-based decision-making is necessary for Big Data, there are still important situations where judgment and experience are very important in decision-making.

Proactive and innovative organizations use experimentation as a risk management strategy when looking for an opportunity to commercialize Big Data. Small and medium-sized companies use Big Data to enrich internal data, and thus improve the decision-making process. Of all resources, human resources are the most important, so it has been confirmed that Big Data has a positive impact on human performance in small and medium-sized enterprises. These are people who will fit into the organizational culture, look for opportunities to use Big Data and who are able to face the various challenges that come with Big Data offerings. In this research, it was assumed that small and medium-sized enterprises, like large corporations, will use Big Data to process and analyze large amounts of data, enrich internal databases with external data and scan the external business environment. However, SMEs are unlikely to have huge amounts of internally generated data. In this paper, none of the small and medium-sized companies that participated use Big Data for these purposes, which does not mean that there are no such cases, but only thatthey are very rare. This could be a big advantage for two reasons. First, small and medium-sized enterprises can avoid the fixed costs of storing internal data that they may not need to use, which is an especially important advantage for them when it comes to resource constraints. Second, recent research indicates that companies that have a lot of success with extracting value from internal data, may experience a delay with the intention of using Big Data to search for information from the environment. In the end, the research showed that decision-making and a strong entrepreneurial orientation definitely have an impact on the implementation of Big Data, but that this relationship is also reversed. Big Data has a positive influence on decision-making, operationalization of processes and entrepreneurial culture. Entrepreneurial leaders with their proactiveness and innovation have proven that maximizing the benefits of Big Data is possible, regardless of limited resources.[19].

In research*Expectations that influence Big Data usage of SMEs Business Entrepreneurs,* [20] which was done in the area of Thailand, it was proven that most managers from small and medium enterprises understand the meaning and advantages of the Big Data concept. They showed interest and attitude that Big Data is a necessary technology for organizations, because the implementation helped their companies to transform business and operations in the digital world and achieve business in the long run. They try to implement Big Data in both online and offline business. There is also an understanding of the need to research information and take the time to invest in people, technology and processes so that everyone can benefit from applying the Big Data concept. Managers expect to use Big Data in full capacity with the goal of achieving the mission and vision of the company. They expect that Big Data will also serve as a tool for solving problems such as increased sales volumes or generating new business opportunities. In a more advanced form, managers want to get support from Big Data in the areas of decision-making, creating demand predictions, inventory management, and deep analysis of user behavior, and in creating promotions and campaigns.

Small and medium-sized companies, in addition to the process of knowing theBig Data concept, also have certain expectations that they can identify and recognize. The first expectation that managers have is to personalize the experience for each individual user. The priority is reflected in retaining and creating user loyalty. Another expectation that has been identified is the help of Big Data in establishing effective prices. The importance of the price of a product/service when it comes to making a purchase decision is recognized, so Big Data wants to be used to analyze user behavior and establish prices accordingly, thereby achieving motivation among users to make repeated and more frequent purchases. The third assumption and desire concerns the conversion of visitors into regular users. Sales industries can use informationabout the online behavior of visitors, especially those who have not yet madeany purchases. It is possible to come to the realization of what prevented them or refused to take that step [20].

The master's thesis *The influence of Big Data on retail activities and retail performance* from 2020 [21], takes as an example of two cases of using Big Data in sales activities, namely in the areas of South Africa and Italy. Both analyzed cases brought different results (Table 5). In the case of South Africa, it is evident that companies have advanced knowledge of Big Data, but that the way of using it is still in the early stages. In South Africa, retailers are still struggling to find the resources and reasons to take Big Data to the next level, while in Italy there is an excellent example of how investing in Big Data management and analytics can pay off, and lead to savings and performance improvements.

Table5. Differences in Big Data Usage[21]

SOUTH AFRICA	ITALY
Retailers do not use real-time analysis	Retailers do not use real-time analysis
Retailers do not analyse unstructured data	Retailers analyse unstructured data
Retailers do not use BD to optimize business processes	Retailers use BD to optimize business processes
Retailers outsource most of the BD analytics	Retailers outsource most of the BD analytics
Segmentation of clients is not performed upon BDA findings	Segmentation of clients is performed upon the findings of BDA

South African retailers explained that the use of Big Data is still in its infancy. Big Data analytics is done internally and continues to be done in a basic way, without an expert data team dedicated to the advanced analytics that would give businesses a competitive edge. Furthermore, the analysis of unstructured data is performed externally, which also indicates a low commitment to data analytics. While big data can offer marketers a huge advantage, it can also bring costs and obstacles that can discourage businesses from using it. This appears to be an issue for South African respondents as they are reported to still be reconsidering the trade-off between investment costs and improved business performance[21].

The first obstacle South African retailers face is the significant capital investment required for Big Data. Investing in big data platforms, hiring data experts and then paying their salaries is a long-term commitment that South African retailers are not yet ready for. Another obstacle they face is the lack of available analytical skills. Finding skilled employees, educated in the field of Big Data and retail, seems to be a big problem. Another possibility is to educate their employees, but that requires time, money and, most importantly, the willingness of their employees to take such a step. Outsourcing Big Data analytics seems to be the preferred option in these circumstances, but the costissue would still be present. However, the biggest problem seems to be the need to justify the costs of implementing Big Data [21].

When it comes to the Italian retailers who participated in the case study, it could be seen that they had already developed an advanced management system with Big Data. Used in various fields, Big Data analytics has increased the effectiveness of companies and reduced many costs to a minimum. Of course, at one point they encountered obstacles that had to be solved by investing significant time, money and resources. It is interesting that the Italian traders who responded to this challenge discovered an excellent solution for finding employees with the necessary skills. It was reported that at the beginning of Big Data implementation, it was difficult to find employees with the right skills. To solve this, managers started working with universities, posting job offers with the required skills for that job. Students would then see the offer, educate themselves knowing that a job awaits them. This method could also be used in South Africa and would help solve the problem of finding employees with the necessary skills [21].

Furthermore, since Italy is a different, more competitive market with more demanding consumers, it was necessary to take steps to introduce Big Data. However, using it turned out to be extremely beneficial for them. In addition, looking at this example, the trade-off between the advantages offered by Big Data and the investment costs proved to be appropriate. Likewise, when comparing the Italian retail industry with the South African one, it could be seen that the level of competition is much higher and more serious in Italy. Evidence to prove this comes only from the fact that most large Italian retailers had to adapt to the use of Big Data as soon as possible in order to maintain a competitive advantage. While in South Africa, no commercial enterprise has indicated the possible implementation of internal Big Data analysis in the near future, as the obstacles are difficult to overcome. That being said, it is possible that as soon as one South African manager implements a more advanced Big Data system, others will follow [21].

As for the knowledge of Big Data, for the South African case it was concluded that the interviewed managers are well acquainted with the values that the Big Data concept can bring, but that the full potential is not used, only a limited part. In the Italian case, all managers expressed high awareness and knowledge of the Big Data concept, approach it without skepticism, are aware of the value they can get from Big Data, and are ‘’open-minded’’ when it comes to use. In terms of usage itself, in addition to many areas that have been improved, managers singled out marketing and the logistics chain as key areas, with huge potential for improvement with Big Data analytics in the future. Data-driven decision-making has also proven once again to be a driver of competitive advantage. When making important decisions, managers take into account the results of Big Data analysis, which significantly reduces the risk of failure. Additional advantages obtained from the implementation are reflected in the improvement of customer segmentation, optimization of processes in the company, optimization of logistics processes, and the use of predictive analytics for planning processes [21].

Another master thesis, *Why SMEs lag behind in big data: an explorative study of Dutch consultancy firms*, from 2019 [22], deals with the question of why SMEs lag behind in the adoption of Big Data in the Netherlands. Primarily, the research results showed that the majority of respondents are familiar with the Big Data concept and that their definitions fit the basics of Big Data. All disagreements, such as using only large data sets, occur due to the vagueness of the term itself. Regarding the success of Big Data implementation, human resources are cited as the biggest barrier. As Big Data is a complex adaptation, it requires expertise and special skills that are difficult to acquire without special training. As a result, SMEs have difficulty finding and retaining the right people to work on Big Data technologies. What enables the successful implementation of a Big Data strategy is the flexibility of the organization when it comes to changes and the implementation of new innovations. An internal organizational culture that is flexible, curious and where experimentation is desirable is considered very valuable in the process of being successful, and recognizing and using opportunities such as Big Data. Big Data is used as an organizational resource in the interviewed sample. The transformation to data-driven organizations has not yet been achieved, but there are aspirations towards it, and it is highly likely that it will happen in the near future. Small and medium-sized enterprises are experimenting with extracting insights and hidden information, which can significantly influence learning and capacity development. For example, the use of Big Data to understand and optimize processes will certainly lead to changes in the routine itself, as well as in dynamic capacities. Big Data currently complements the decision-making process for SMEs with evidence and data. Table 6 shows all the projects that the interviewed managers consider to fall under Big Data. It also shows how Big Data is applied. Among the 14 SMEs interviewed, 9 of them can be said to be using Big Data, while the rest have no active projects that can be classified as Big Data [22].

Table 6. Application of Big Data in Dutch SMEs
(Source: [22])

Firm no.	Description of big data	Which V's?	Big data?	Application
1	Not size, but the use case is important	Volume	Yes	Process optimization with multiple goals: customer experience, working more efficiently, saving costs
2	Something that does not fit in excel and cannot be processed on a single computer	Volume	No	Maintenance of technological infrastructure and (B)DAaaS
3	Data with half a million rows	Volume	No	Increasing validity of product (advice) with data
4	Big data is predicting, difficult data is about volume	Volume	Yes	Increasing validity of product (advice) with data
5	Hundreds of thousands of photos	Variety, Volume	Yes	Improving customer experience
6	Data on three hundred thousand people	Volume	No	Increasing validity of product (advice) with data
7	Five hundred million rows per day	Volume, Velocity	Yes	Increasing validity of product (advice) with data
8	Collection of structured and unstructured data	Variety	Yes	Increasing validity of product (advice) with data.
9	Using advanced statistical analyses	Volume	No	Process optimization with multiple goals: customer experience, working more efficiently, saving costs
10	Connecting different data sources	Variety	Yes	Extracting (hidden) insights from big data
11	Unstructured data with no use in mind that is transcending more than one application	Variety	Yes	Extracting (hidden) insights from big data
12	Too large to use on a single computer	Volume	No	Process optimization with multiple goals: customer experience, working more efficiently, saving costs
13	Reach of 1.7 million people	Volume	Yes	Targeted marketing
14	Connecting systems with multiple data sources to each other. Has data on 3.5 million people	Volume, Variety	Yes	Process optimization with multiple goals: customer experience, working more efficiently, saving costs

We must bear in mind that global market-technical-technological trends are eroding the dominance of large companies over small ones, and that flexible and technologically savvy companies with adequate strategies (and financial support) have a real chance to get closer to the market leaders and tackle the battle for market shares[23]. Research by Lufti et al. from 2022 [24] was aimed at identifying the determinants of Big Data application in the context of a developing economy on the example of Jordan. The authors analyzed the influence of technological, organizational and environmental factors on the application and adoption of Big Data in the context of Jordanian SMEs, using PLS-SEM for analysis. As a theoretical basis for the research, a hybrid modelwas developed for the analysis of factors influencing the adoption of Big Data by combining the technological–organizational–environmental (TOE) model and diffusion of innovation theory (DOI) as the theoretical foundation. In the mentioned model, the Technological Factors included: Relative Advantage, Complexity, Compatibility and Security; Organizational Factors included: Top Management Support, Organizational Readiness, and Environmental Factors included: Competitive Pressure and Government regulations. Empirical results showed that Relative Advantage, Complexity, Security, Top Management Support, Organizational Readiness and Government regulations influence BD adoption.For the factors Competitive Pressure and Compatibility, the influence on the adoption and implementation of Big Data in the research of Lufti et al. from 2022 has not been confirmed. The authors identified top-management support (''in the form of sufficient financial and technical support, employment of suitably skilled employees and provision of relevant training for current employees'' [24]) and government regulations as the most important factors supporting the adoption of Big Data by SMEs.

A research team from Pakistan, Igbal et al. [25] directed its research into the practice of adopting Big Data technology in SMEs to identify the main potentials and threats in the process of using Big Data Analytics and determining the best practices in the use of Big Data Analytics in small and medium-sized enterprises. The authors focused on the following questions: awareness of the possibilities offered by BD, the availability of DB experts, the availability of computer infrastructure for storage, processing and production of functional information from DB, availability of consulting services for Data Analytics, availability and development of the software market, lack of User-friendly, Economical Software, security and privacy issues, Lack of Business Concept and Organizational Structure suitable for exploiting the potential of Big Data,and the availability of financial resources to support the finalization of these processes as well as appropriate legal regulations. The authors particularly emphasize that small and medium-sized enterprises must undertake cultural changes if they want to take advantage of the potential of Big Data. This requires that SMEs identify the tools and methods for handling the data available in the environment and be ready to use all the potential that Big Data offers for decision-making processes. However, using the opportunities offered by Big Data simultaneously implies facing different challenges at different levels for all participants: national and international policy makers, the IT community, the business community and the academic community in accordance with the principles of the Triple-Helix Model [26, 27, 28].

In 2020, a team of Indian scientists [29] addressed the identification of the mediating role of BDA in the influence of nine factors: top management, project knowledge management focus on sustainability, green purchasing, environmental technologies, social responsibility, project operational

capabilities, project complexity, collaboration and exploratory learning, and project success on ‘’Project Performance’’. The results of research conducted on a sample of 321 responses from 106 Indian manufacturing small and medium-scaled enterprises ‘’shows that project knowledge management, green purchasing and project operational capabilities require the mediating support of big data analytics. The adoption of big data analytics has a positive influence on project performance in the manufacturing sector’’ [29]. The research underlines the importance of eliminating difficulties in the adoption of BDA and formulating strategies for effective project management in small and medium-sized enterprises adapted to the specific contexts of enterprises and economies in which these enterprises operate.
Similar to the previously described research, the duo Seseni and Mbohwa from South Africa [30],based on desk research of secondary data, identified in their research the key effects of Big Data application in SMEs: productivity, profitability, business innovation, efficiency and creation, sophisticated skills, mining and analyzing data, but also the key problems faced by SMEs in extracting benefits from BDA, which are reflected in the difficulties of using Big Data tools and technologies. The authors suggest that academic and governmental institutions should develop appropriate support programs to overcome these difficulties. Universities should develop and implement education programs to train small and medium-sized enterprises in the use of BD tools and technologies. The government should develop financial and non-financial support programs for SMEs so that they can acquire and use advanced technologies necessary for competitiveness in modern markets. Additionally, the academic community and BD practitioners should work to develop BDA tools and technologies tailored for SMEs to provide them with the technical and technological support necessary to compete in today’s market [30].

5.3. Conclusion of the research

Through inductive thinking, we can draw the conclusion that small and medium-sized companies, using the Big Data concept, realize numerous improvements in their daily business, both in internal and external processes. All this is possible, if and only if the implementation of the Big Data concept has been successfully finalized, if all challenges have been resolved, if responses to potential risks are ready and if the knowledge of the Big Data concept is at the desired, predicted level. Small and medium-sized companies are generally familiar with what Big Data is and what this concept can mean for their position and their future business. Small and medium-sized enterprises with leaders who have an entrepreneurial mindset and are motivated by growth, have a reputation for being more agile and better at exploring market niches than their competitors, which include large corporations. Although they have limited resources, theystill have a great advantage in using the opportunities that Big Data analytics can identify for them. In general, we can conclude that all research shows that Big Data strategy in small and medium-sized companies has positive correlations with decision-making and company orientation. The availability of clod services, as well as online tools, allows small and medium enterprises to go beyond the expected and develop an absolutely new business model that will allow them to create analytical and operational skills identical, if not greater, as is the case with large organizations. Managers, with their proactivity and innovation, can very well recognize and take advantage of the advantages that Big Data will present, regardless of the limited resources that most small and medium-sized enterprises struggle with. The fact is that even limited resources can force companies to innovate that larger competitors haven't even thought about.

The implementation of Big Data in small and medium-sized enterprises not only affects the business itself, but also has a positive impact on all other organizational and business factors of the company, from the internal culture, process efficiency, human resources and the very operationalization of the business.

Small and medium-sized enterprises and their leading managers are familiar with the meaning of the Big Data concept, and can identify the benefits that will be obtained by implementing the strategy. The significance, importance and desire for implementation was recognized, all with the ultimate goal of long-term survival and market dominance.

Big Data facilitates all internal and external business processes of small and medium-sized enterprises, shortens unnecessary processes, enables an easier flow of information through the enterprise and helps deliver better products/services to the market.

6. Conclusion

Today, when every decision is based on experience, and all companies, regardless of their size, are fighting for the loyalty and favor of clients, as well as for differentiating their brand on the market, there is nothing more valuable than the data itself. Data provides the insights needed for constant growth and advancement. Big Data, as a concept that has changed and progressed over time, finds its use in every modern enterprise, both in large corporations and in small and medium-sized enterprises. With the right analytics, technology and tools, as well as people and ideas, there is nothing businesses can't accomplish or achieve. All this is possible only if Big Data is viewed as a collection of several separate items, each of which carries equal importance. This concept is not an end in itself, and it is necessary that all elements function smoothly, so that it can be said that Big Data works together with us, in the realization of our mission and vision. In addition, this concept puts the primary focus not on the data itself, but on the technologies, processes, tools and people who will work with this data and extract the maximum value, knowledge and profit from it. Big Data does not belong only to large corporations, nor can anyone claim this concept as their property and copyright it. That is why it is very important that small and medium-sized enterprises, as pillars of state economies, familiarize themselves with this concept, with all the opportunities and possibilities that the implementation of Big Data strategy will bring to their business. Small and medium-sized enterprises, regardless of numerous limitations, financial and operational, should not avoid new approaches in their business, but rather the opposite: look for examples and inspiration in the good practices of large enterprises, and learn from the best. Based on the research results, we have seen numerous positive impacts that Big Data has for small and medium-sized companies, and of course, we can also find additional inspiration in the examples of market leaders. Big Data is already becoming, and it can be assumed that it will soon become a standard in the business of small and medium-sized companies. The future that lies before us definitely depends on us and the technologies we use to facilitate and improve people’s lives in every possible way. With proper use, with the necessary skills, knowledge, vision and creativity, as well as the technologies at our disposal, the world that lies before us will become a pleasant, bright, warm and desirable place for every human being.

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Organizational Changes and Work Design in the Context of Industry 4.0 – A Paradigm Change

Elvir Šahić[*1], Mirha Bičo Ćar[1], Savo Stupar[1]

Abstract: *Industrial production is currently experiencing a revolutionary transformation through digitization processes and networked technology, so that it necessarily goes through a series of essential changes, which require conceptual design and creation of new terms. In the field of social organization of work, the processes of management and control are experiencing radical changes, and many novelties that bring technological innovations provide the opportunity to analytically observe the interaction relationships of different systems, without losing individuals, organizations and society in the context. Given that digital transformation is not a uniform process, the paper presents the advantages of a holistic approach in the analysis of organizational changes. New ways of organizing work bring various kinds of challenges that must be understood in order to be able to detect the social mechanisms that are at the very basis of change. The paper points out the specific social dimensions of technology that appear during the creation of organizational processes within the framework of the Fourth Industrial Revolution. The very term 'industrial revolution' is understood in the paper in a broader sense, and includes changes in social relations and the status of certain social groups, and not only changes in the production process and factors of production. The paper explains the status changes in power that are connected with the possibility of making business decisions in various forms of organizational practices, showing the increasingly pronounced complexity of interactional relationships between people and technology, which points to the necessity of interdisciplinary observation and finding a holistic approach to understanding the nature of the changes that are taking place.*

Keywords: *organizational logic, work design, organizational changes, flexibility, networking, Industry 4.0*

1. Introduction

Changes related to the transformation of industry through intelligent networking of machines and processes with the help of information and communication technology (ICT), represent global trends that we denote by the term Industry 4.0 or The Fourth Industrial Revolution. The very meaning of the term aims to emphasize the radicality of the changes brought about by the digital transformation of the industry, since the changes are revolutionary in almost all

[*1]University of Sarajevo, School of Economics and Business, Trg oslobođenja 1 Sarajevo
E-mail: elvir.sahic@efsa.unsa.ba

spheres of social life. The constant reconfiguration of the relationship between phenomena accompanied by increasingly frequent ''industrial revolutions''emphasizes the need for a new conceptualization of the reality that constantly eludes us in its exponential growth of technological innovation.

The need to find new conceptualizations shows us all the dynamism of changes that technological innovations bring with them. Thus, with the intensification of the use of ''smart'' technologies and algorithmic control guided by artificial intelligence (AI), the forms of interdependence between people and machines are radically changing. The increasing autonomy of different systems on the one hand, as well as the increasing connectivity through networking, on the other hand, mean that the established ways of designing organizational management and control practices are becoming increasingly inadequate. This is especially expressed if we look at the ways of organizing work and the processes of speeding up business decision-making.

In this paper, we want to point out certain social dimensions of technology that arise when designing organizational processes within the framework of the Fourth Industrial Revolution. We interpret the term ''industrial revolution'' in a broader sense than the technical-technological definition, in the sense that it includes changes in social relations and the status of certain social groups, and not only changes in the production process and factors of production. In our case, status changes refer to changes in power that are associated with the possibility of making business decisions in different forms of organizational practices. Starting from this sociological understanding of the concept of industrial revolution, we want to point out the increasingly pronounced complexity of interactional relationships between people and technology, which points us to the necessity of interdisciplinary observation and finding a holistic approach to understanding the nature of changes. [1, 2, 3]

By emphasizing the social dimension of technology, we want to point out that changes in the way work is organized are largely of a probabilistic nature, because,ultimately, they depend on the interests of different groups of people and are connected to certain social mechanisms. In this way, we can interpret specific reconfigurations of the social division of labor in the processes of digital technology integration through all areas of business in the context of the further development of ''networked social reality'' which is a key characteristic of the information society [4]. The basic unit of economic organization of society becomes the ''network''. This network is composed of a multitude of subjects and organizations that are constantly reshaping. The main requirements for reshaping are found in the need to adapt to market structures and the environments that support them. [4]. The changing geometry required by

‘’informationalism’’ is characterized by a social state of ‘’fluidity’’ [5] in which any attempts to crystallize position in the network as a ‘’cultural code’’ are condemned to obsolescence.

We observe the digital transformation from the point of view of the design of organizational, business and work processes that are made possible by digital data, algorithms and computer infrastructure. Our main goal is to point out the aspects of informatization and ‘’smart’’ automation as radically new forms of change that increase the growing share of autonomous activities under the control of algorithms as opposed to the expertise of people. The changes make a more visible difference between traditional processes that relied on social interaction and decisions and digitalized processes that depend on algorithms and data flows [6]. The basic premise from which we start our paper is contained in the opinion that ‘’networking’’ gives us the opportunity to question the conceptual foundations on which the new organizational logic is based.

2. New Organizational Logic - Global Trends

On a global level, different types of organizations are experiencing transformations due to the redefinition of business models in the conditions of an increasingly dynamic environment. The business environment characterized by multiple ‘’networking’’ changes the character and nature of business, bringing with it new perspectives. [7, 8] In the organizational context, a series of changes occur that reshape the ways of performing work and affect the design of the work environment. We can observe the new organizational realities through the prism of a ‘’networked logic’’ whose basic characteristic is the intensification of the flexibility process.

The processes of intensification of flexibility can be singled out as one of the key characteristics of organizational changes followed by digital transformation within the framework of the Fourth Industrial Revolution. In this sense, we will refer to the explanation of the ‘’new organizational logic’’ that Johannessen [9] presents through two specific characteristics, defining them as ‘’Lego flexibility’’ and ‘’experience design’’.

In the sphere of production, ‘’Lego flexibility’’, among other things, implies widespread business practices where the production chain extends to a certain number of countries in accordance with costs, quality, innovation and logistics competence. By the same logic, ‘’the administrative system, as well as the various roles of the company’s staff members, can also be considered external. [9: p. 41] The production of each product is broken down into its component parts and is located in places ‘’where the price is low, the quality is high, the competence is excellent, and the rate of innovation is above average and high''. Depending on these four elements, the production of individual components takes place in different parts of the world in order to combine them to form one final product. [9: p. 42]

The processes of wealth creation through lego flexibility give a new perspective on productivity, changing its character from the logic of production to the logic of global clusters of competences. [9: p. 45] Productivity can be measured with innovation within new network constellations. The unpredictability of global trends brings with it challenges that call into question the concept of productivity that was determined in the traditional way. Thus, according to Johannessen, turbulence and new organizational structures encourage the development of new concepts that represent indicators for measuring productivity, such as: ''innovativeness, flexibility, adaptability, relational and network competence, and resolution of complexity and ambiguity'' [9: pp. 44-45] The organizational form of *lego flexibility* consists of multifunctional teams that make up the smallest units, while global clusters of competences make up the global unit. In the organizational sense, it is very important to dedicate yourself to the development and transfer of knowledge, feedback processes, joint creation and analysis of social sentiment. [9: p. 42] All this in the context of intensifying global competitiveness leads to the development of global networks of competences that highlight the importance of the role of relationship networks in the achievement of success. This is true both for individuals, i.e., on an individual level, and on a corporate level, since network relationships will enable co-creation, both between individuals and between customers and businesses''. Supported by robots, informats[†] and artificial intelligence (AI), the development of ''lego flexibility'' will require new competencies and new forms of cooperation.
One of the main goals of the new organizational logic, according to Johannessen, is contained in assuming responsibility and encouraging the development of creativity in ''the environment and the global network of competences, in order to create innovations''. The basic assumption for the achievement of this goal is the acceptance of an innovative model of management and organization whose focus is processes aimed at supporting people who are on the ''frontline'', that is, ''processes and connecting

[†]By "informats" Johannessen [9] means robots with artificial intelligence (AI) that are interconnected in a global technological network. According to him, ''informats'' appears as emergent robots, and as such ''can sense, analyze and make decisions within one microsecond''[9: p. 101].

customersand workers who do what the organization is designed for'' (known as ''core activities''). Johannessen [9] defines this organizational principle as ''experience design'', which is another characteristic of the new organizational logic in the context of the Fourth Industrial Revolution.

One type of experience-based design is known in the field of service innovation and has previously been used as a model to achieve the required scale of change, and has also been referred to as ''co-design'', ''participative'' or ''interactive'' design. The main characteristic is that the traditional view of the service user as a passive recipient gives way to the view of the user as a co-designer and as an integral part of the process of improvement and innovation. The purpose is to allow designers to focus primarily on the experiences created, rather than the service being delivered. [10: p. 89]

According to Johannessen [9], ''experience design'' implies that people on the front line can make decisions in real time, and it is necessary to focus organizational processes on two aspects in particular. First of all, ''competence and maintenance of competence on the front line'' is singled out, which refers to individual and team competence. In addition to these two competencies, the business organization is equally important, which enables the ''frontline'' to have constant support, service and help from all levels of the organization. Secondly, optimal coordination between activities is necessary to harmonize relationships at the system and network level. The focus is on the organization of the process where customers, users and citizens (the public) are located in a center that is organized around the first line. For this reason, Johannessen [9] uses the name ''experience design'' because, in his opinion, the experience that is significant is acquired and happens between customers/users of services and people on the front line. [9: p. 46]

In this way, the key factor for creating wealth and connecting to creative and innovative networks is competence on the front line, according to which it is necessary to develop mechanisms that will use the ''flow of experience'' to ensure the survival of the system. Competence on the front line is reflected in the speed, flexibility and skill of making decisions in real time, which with new technology (robots, AI and informats) enables individualized and customized solutions. The new technology enables a completely individualized relationship with each customer/user regardless of the fact that the customer base, as well as the variety of what they are looking for, is constantly growing. ''The profile of the individual will form the basis for referring the company to the client, and the customer will generate his profile through contact with the company. This experience design will then create wealth for both clients and organizations''. (''The individual's profile will form the basis for a business's referrals to the customer, and the customer will generate their profile through contact with the

business. This experience-design will then co-create wealth for both the customers and the organizations''.) [9: p. 48]
We can find these examples of individualization in various areas such as, for example, media, medicine, music, entertainment, computer software, clothing industry, education, etc. [8, 11] Such adaptation to individual users and customers requires an innovative system that would be focused on constant changes and coordination between different systems. As one of the consequences of individualized adjustment and upgrading of competences in the front line, we can single out the transition from hierarchical management and control systems to more vertical systems of organization and management. An illustrative view of organizational design changes is presented in Figure 1.

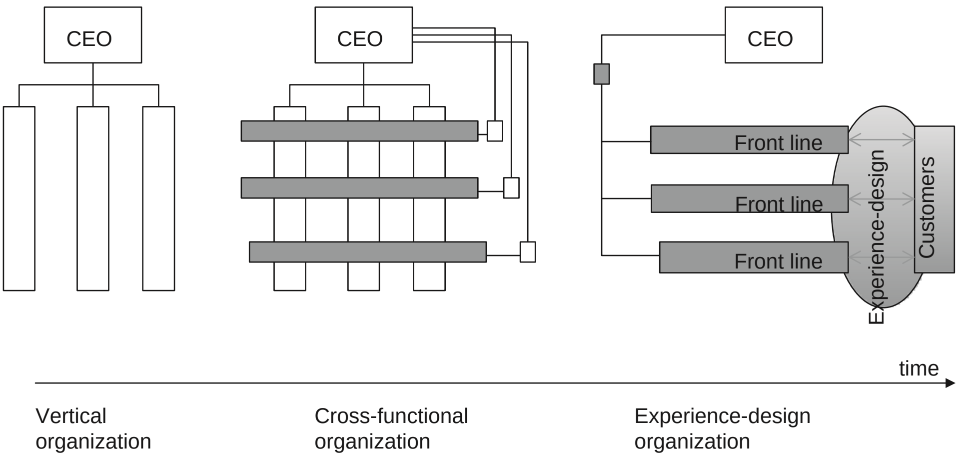

Figure1.Schematic representation of organizational design changes (Source: [9: p. 47]*)*

According to Johannessen [9], the key features of the new organizational logic refer to: process organization, de-bureaucratization, team organization, a large degree of external structural connections, and the continuous development of competencies at all levels. In this sense, we can observe the improvement of worker efficiency, first of all, as a result of new organizational logic, and not primarily of new technology. ''The new robot technology and the systemically linked informats, and even the nano-computers, will be the unifying glue in the organizational spider's web, which holds everything together in a very strong, systemically linked system'' [9: p. 50] The key change is in the way of organizing work and management [12] in the context of new methods of production, distribution and consumption that bring with them new forms of technology in the form of robots, ''informats'' and artificial intelligence. In thefollowing part of the paper, we will consider certain changes in the ways of organizing work, taking into account the different levels of manifestation of these changes.

3. A Holistic approach to organizational changes and working environment design

The landscape of digital transformation of industrial production is illustrated by the current trends of automation and data exchange in production technologies, such as: cyber-physical systems (CPS) which include machines, devices and robots connected via the Internet where management is performed through computer algorithms; the Internet of Things (IoT), which refers to the connection of all physical places and things to the Internet; cloud computing and cognitive computing, and the creation of a smart factory[13]. As a new business paradigm, the application of Industry 4.0 is represented in many industry sectors [11].

What we especially want to highlight is that in the context of digital transformation, the processes of information, communication and networking, both within and between companies and business systems, bring special challenges related to the possibilities of designing work. By work design we mean the way in which people are arranged in a certain organization or institution, and the way in which jobs are performed and the different types of tasks and interactions that these jobs include [14].

In this sense, together with Hirsch-Kreinsen & Ittermann [14], Industry 4.0 can be seen as a design project that, among other things, includes different alternative views on the relationship between work and technology. Various alternative views are represented in the tradition of sociological research whose findings show us that there is no linear relationship between the phenomenon of work and technology. In addition, instead of a one-sided deterministic relationship, whether it is technological or social, complex and reciprocal relationships are presented that are shaped by the influence of multiple social, economic, political, labor-legal factors. These multiple factors ultimately determine how new technology will be adopted and how it will shape the future of work. [14]

The conceptual basis for the analysis of [14] finds a socio-technical approach which, according to them, can serve us in the most convenient way when formulating a suitable framework for work design in digital conditions of industrial production. The authors find the advantage of this approach in determining the socio-technical system, which, despite the inconsistency in definitions, can be understood as ‘’a production unit consisting of interdependent technological, personnel and organizational subsystems’’ [Trist &

Bamforth,1951; Rice, 1963; cited by: 14: p. 279]. Despite the fact that the technological subsystem can limit the design possibilities of the personnel and organizational subsystem, these two subsystems have independent characteristics that influence the functioning of the technological system. In this sense, the relationship between the subsystems is reciprocal and probabilistic, and in this way the socio-technical approach emphasizes the interactions and mutual dependence of technology, people and the organization as a whole.

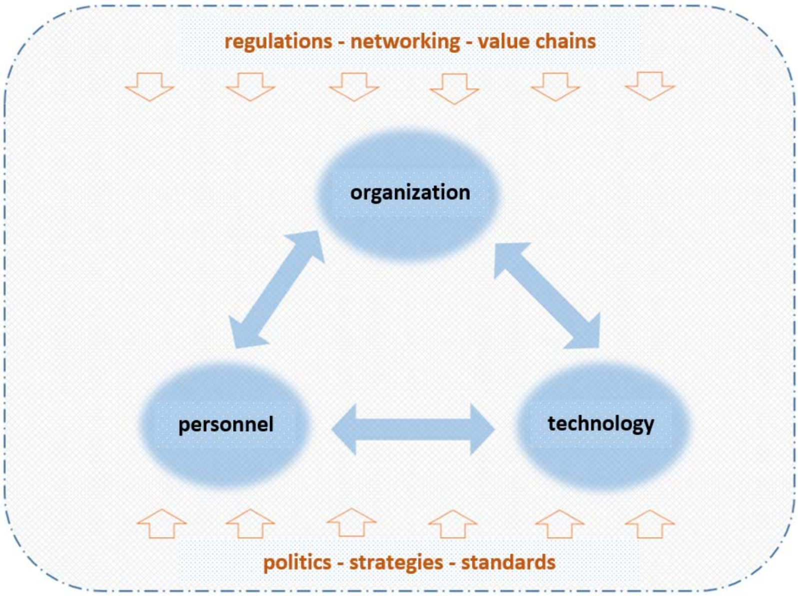

Figure 2.A holistic presentation of the socio-technical concept of work design (Source: authors according to [14: p. 279])

If we look at the socio-technical system in the context of digitization and Industry 4.0different subsystems, according to [14], we can determine that technology includes ‘’innovative transport technologies’’ and ‘’smart objects’’ that manage themselves through production processes. Personnel as a subsystem includes skill requirements, employment structures and employee participation modalities. Organization as a subsystem would refer to changed workplace structures, new management functions and innovative business models. Additionally, the work design in its entirety should take into account the economic requirements of various application fields and knowledge domains of Industry 4.0. Around that, ‘’the socio-technical system is embedded in the strategic and institutional framework and factors of the socioeconomic context’’ [14: p. 279]. In this way, we can adapt the traditional view of organizations as

socio-technical open systems [15] because interaction with the environment forms an integral part of work design.
Another conceptual advantage of the socio-technical approach is reflected in the possibility of harmonizing correlative social and technical subsystems through ''joint optimization'' [16], which emphasizes the principle of the reciprocal relationship between work, organization and technology. This once again underlines the inadequacy of the deterministic view. In the following, we will consider a conceptual framework of basic guidelines for human-centered work design based on the key findings presented in the work of Hirsch-Kreinsen & Ittermann [14].

4. Basic Guidelines for Work Design

In accordance with the concept of a socio-technical system, we can observe changes in the way subsystems interact under the conditions of application of digital technology. As an example of the key characteristics of the Fourth Industrial Revolution Hirsch-Kreinsen & Ittermann [14] present a work design that would include correlations between technology and personnel, personnel and organization, and technology and organization.

The first correlation ''technology and personnel'', starts from the essential question that refers to new forms of ''distribution of functions and interaction between machine and man''. The necessity of a holistic and collaborative view of human-machine interaction that ''identifies specific strengths and weaknesses of human work and technological automation'' is stated as a basic requirement. Due to the expansion of the scope of automation (through smart technology), according to Hirsch-Kreinsen & Ittermann [14], the central goal that human work should achieve and preserve is transparency, as well as control possibilities over production processes. At the same time, it is important to develop much-needed practical knowledge that should be supported by intelligent assistance systems. Hirsch-Kreinsen & Ittermann [14], state two basic criteria for designing new forms which they formulate as: ''sensitivity to context and adaptability'' and ''complementarity''.

Sensitivity to context and adaptability - should include changes in the spectrum of employee tasks due to ergonomically oriented adaptation of digital systems to specific working conditions. ''An intelligent ability to adapt information systems and help individual, partially different skill levels of workers is necessary, in order to ensure opportunities for continuous learning and qualification processes on the staff side'' [14: p. 284.]. ''Necessary is an intelligent capability to adjust the information and assistance systems to individual, partly differing worker skill levels, in order to thereby ensure on the personnel side, the possibilities for continual learning and qualification processes'' [14: p. 284.].In other words, it is necessary to alleviate the consequences of diminishing the importance of the practical knowledge of employees and to ensure the processes of continuous learning and qualifications.

Complementarity - refers to the flexible division of functions in human-machine interaction in order to ensure sufficiently transparent and controlled ''smart'' systems given to employees. This principle would allow digitally supported real-time decision-making and employee behavior options to be secure and changeable. ''The relevant design aspects are here: to provide human-machine interaction through intuitive serviceable hardware that can quickly be learnt, as well as targeted access to real-time digital information for specific situations, thereby enabling digitally supported decision-making and employee behavior options as safe and changeable''. [14: p. 284.] ''Relevant design aspects are here: assure human-machine interaction through intuitively serviceable and rapidly learnable hardware as well as targeted and situation-specific access to digital information in real time, in order to make thereby the employees' digitally supported decision-making and behavioral options secure and modifiable''. [14: p. 284.]

In the context of the mentioned criteria, we are shown that in digital transformation, technology is not a passive object that is manipulated, but an active subject that behaves in a way that requires constant specific establishment of decision-making competencies. ''The interaction between smart systems and worker behavior can generally be characterized as hybrid'' [14: p. 284.]. According to the author, this brings us to a controversial issue related to the interaction between man and machine, and it concerns responsibility. Namely, the question is: to what extent, in human-machine interactions, can we talk about 'machine responsibility' as equal to 'human responsibility'. [14: p. 285.]There is no doubt that this remains an open question that leads us to consider a number of ethical and other social aspects of modern life and work. Together with the authors, we can agree that it will gain more and more importance due to the increasingly dynamic intensification of the autonomous systems of Industry 4.0.

The second correlation, ''personnel and organization'' is presented in relation to changes in the ''scope of action and model of working hours, and new requirements in terms of training standards and skills''. The key issue here is the way in which the organizational design of work in I4.0 will enable the use of competencies and empirical knowledge of employees in the context of developing the range of activities and continuous learning through the acquisition of various qualifications. The design of the work would include the multivalent disposition of workers and the processes of acquiring relevant skills and knowledge during the actual performance of the tasks.

The central characteristic of tasks is that they are less and less individual, i.e., addressed to one worker, and more and more team-based, i.e., addressed to working teams. This team character of the task influences the working teams to ''act self-organizing, highly flexible and situationally determined according to the problems that need to be solved in the technological system''. 14: p. 285.]. Likewise, the absence of strictly defined tasks requires organizational forms that can coordinate loose networks of qualified and differently specialized workers. In this way, the flexible integration of work could be subsumed under two key characteristics: ''holism'' and ''dynamism''.

Holism - this criterion means the organization of work activities in a holistic sense in a way that includes types of tasks that, in addition to executive tasks, also include dispositive tasks such as organization, planning and control. Similarly, it includes a combination of tasks according to their demands in order to enable the reduction of workload and the achievement of greater freedom of action and self-organization of work in the context of new forms of cooperation between robots and humans.[14]

Dynamism - on the basis of this criterion, within the design of work organization, they could influence the realization and encouragement of learning at the workplace. In addition, it is necessary to take into account the new functions of social media that ''promote interdisciplinary communication and cooperation between differently specialized employees'' and thus ''increase the innovative capacity of work''. Considering the speed of technological changes, it is important to be able to ''try it in the shop'', and at the same time respond to the demands of loosely structured forms of work in such a way as to achieve the engagement of employees of different abilities and capacities. In dealing with various contingencies, loosely structured and dynamic work processes should be a good basis for making effective decisions and interventions.

The third correlation of ''**organization and technology**'' implies new design options that would include comprehensive structural changes in the work organization of the entire company. The changes concern ''the direct value chain in terms of functions and hierarchy, and the structuring and connection between key production processes and management and support processes''. Here, the main focus is on the decentralization of the organization's segments in the form of exploiting the potential of decentralized digital technology and autonomous production and logistics systems. The organization of the company acquires ''permanent flexibility'' through new technological systems of highly individualized production. Related to this are changes in management functions that are a consequence of changes in decision-making competencies and a focus on employee participation.

The realization of the possibilities of new forms of value chain structures and business models due to the networked system of planning and control, and the application of data mining methods, leads to the creation of industrial values that

are not limited to what happens within traditional organizational boundaries. Reciprocal connections between technology and organization in the ‘’smart networked company’’ create new types of work design challenges that should respond to the organizational requirements of overcoming company barriers in digital transformation processes [14].
Here we could single out, as an example of new challenges, the application of complex systems in production such as Cyber-physical Systems - CPS. They make industrial systems capable of communication and networking, which can then be added to new production capabilities. Communication capabilities are reflected in the fact that they contain intelligent control systems and built-in software, and thus can be connected to a network of cybernetic systems[13].It is basically a computer system where mechanisms are controlled and monitored by algorithms. In addition to industrial control systems, some examples of applications are smart grids, autonomous car systems, medical monitoring and robotic systems. [17: p. 4; 7]
Therefore, we can see that the relationship between the organization and technology is the main emphasis on the processes of system decentralization, which emerge as key guides in designing work. In this way, the extracted correlation relations of the subsystems with certain work design guidelines givenby Hirsch-Kreinsen & Ittermann [14] provide us with a series of further insights into the types of changes brought about by digital transformation.
What we could single out as key to understanding the new realities of the work environment are the presented work design possibilities that would holistically treat a number of issues of different interaction relationships in new forms of industrial production.

5. Conclusion

If we look at the digitalization of industrial production in the way of the revolutionary transformation brought about by networked technology, we can see a series of changes that require conceptual design and the creation of new terms. Many novelties that bring technological innovation provide us with the opportunity to analytically observe the interaction relationships of various systems and subsystems, taking into account individuals, organizations and society as a whole. In the field of social organization of work, management and control processes are experiencing radical changes.
In the context of general global trends of change, we can single out the need for a new organizational logic that would correspond to the networked reality with stated requirements for support processes for qualitatively different relations between workers and machines (robots). In the organizational sense, on the one hand, it is necessary to enable conditions for the continuous improvement of workers’ knowledge and the acquisition of skills (digital data management

competencies, symbolic knowledge) and, on the other hand, to enable decision-making processes in ''real time'' with the support of ''machine learning'' andartificial intelligence. Designing organizational processes would imply that we have in mind a special type of flexibility that, based on networked communication, can harmonize the interactional relations between man and machine. We have to bear in mind that human expertise and algorithmically controlled processes are inherently different.

Respecting all the diversity of digital transformation, the paper tried to present the advantages of a holistic approach in the analysis of organizational changes. New ways of organizing work bring us various kinds of challenges that must be understood in order to be able to recognize specific social mechanisms that are the basis of changes.

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Revolutionizing Healthcare - Exploring the Transformative Power of Automation and AI

Adna Softić*[1], Elma Imamović[1], Emina Mrđanović[1], Lejla Gurbeta Pokvić[1]

Abstract: *In the pursuit of optimizing healthcare delivery and improving patient outcomes, the field of healthcare is undergoing a transformative shift from a reactive approach to a proactive one. This shift is facilitated by two upcoming technological developments: automation and artificial intelligence (AI). The abundance of data generated in the era of digital advancement presents both opportunities and challenges for healthcare. This paper explores the application of AI and machine learning in healthcare, focusing on the challenges posed by the exponential growth in data volume, the analysis of unstructured data, and the rapid pace of data refreshment. It examines the role of AI and machine learning in generating clinical decision support, uncovering disease subtypes and prognostic markers, and generating new hypotheses. In addition, this paper highlights the transformative potential of automation, AI, and robotics in healthcare, showcasing their ability to enhance efficiency, accuracy, and precision in patient care. By embracing these technological advancements, healthcare can achieve continuous progress in meeting the ever-growing demands and aspirations of the field while improving patient outcomes.*

Keywords: *automation, AI, healthcare, robotics*

1. Introduction

In the pursuit of continuous progress in enhancing our capacity to efficiently and effectively accomplish work tasks while minimizing redundant efforts and maximizing performance, which is a universal aspiration transcending generations and scientific disciplines, the field of healthcare is undergoing a transformative shift from a reactive approach to a proactive one [1]. This transformation is being facilitated by two upcoming technological developments: automation and artificial intelligence.

The era of digital advancement has brought forth a wealth of data, coupled with significant strides in computing power for data collection, storage, and connectivity. This abundance of data has unleashed immense potential for data exploitation, creating an unprecedented opportunity for innovation in the field of data science. As a result, the discourse surrounding artificial intelligence (AI), machine learning (ML), and automation has become highly intense.

*[1]Verlab Research Institute, Sarajevo, Bosnia and Herzegovina
E-mail: adna@verlabinstitute.com

When we consider the application of these technologies in healthcare, three data aspects have sparked particular interest. Firstly, the exponential growth in data volume presents both opportunities and challenges. The vast amounts of data generated can create efficiencies, reduce costs, and generate ever larger and more complex datasets. Secondly, a substantial portion of the available healthcare data is unstructured, further complicating its analysis and utilization. This unstructured data includes medical notes, imaging reports, and other textual or visual data that require advanced algorithms to extract meaningful information. Lastly, the rapid pace at which data is refreshed poses significant hurdles to traditional statistical methodologies [2].

Artificial intelligence, as defined by Barr and Feigenbaum, encompasses the realm of computer science concerned with the design of systems that demonstrate characteristics associated with human intelligence and behavior. In the context of healthcare, artificial intelligence can leverage automation and machine learning to process and analyze vast amounts of data, generating clinical decision support, uncovering disease subtypes, associations, and prognostic markers, and generating new testable hypotheses [3]. Machine learning, on the other hand, empowers computers with the ability to learn without explicit programming, enabling them to adapt and improve their performance over time [4].

Automation, in the context of healthcare, refers to the delegation of tasks to machines or computer systems, alleviating procedural burdens [5]. By automating repetitive and time-consuming tasks, healthcare providers can focus more on patient care and complex decision-making processes, while ensuring efficiency and accuracy.

2. Work Processes, Technological Automation and Cutting-Edge Healthcare Delivery in the 21st Century

Healthcare in the 21st century encompasses intricate tasks and the management of vast amounts of data. The delivery of healthcare involves interconnected workflows encompassing clinical, administrative, and population-level processes [6]. These workflows involve various individuals such as patients, caregivers, clinicians, and staff, and are referred to as the sequence of tasks performed within and between work environments [7]. The digitization of paper-based workflows without proper adaptation has created an ecosystem that contributes to burnout and hinders the full utilization of technology for optimizing patient care through automation. Inefficient workflows pose a widespread challenge affecting everyone in healthcare, including clinicians burdened with caredelivery tasks and patients and caregivers dealing with complex care management responsibilities.

The increasing adoption of health information technology (IT) and the availability of modern computational technology offer opportunities for more effective and efficient workflows through automation. Automation, which involves using technology to monitor and control the delivery of products and services, can enhance efficiency in healthcare delivery across different domains (Figure 1). However, healthcare has not fully embraced automation in the same way as other industries. Valuable insights can be gained from the application of automation in non-healthcare sectors, offering lessons that can be applied to healthcare [8].

Figure 1. Areas within healthcare that can be automated [9]

3. Use of DL and ML in Healthcare

The essential difference between deep learning (DL) and machine learning (ML) is the methodology they employ in their systems, the amount of data and the way it is structured. The mentioned differences are the exact reason for DL being more accurate than ML, whereby it is more commonly applied or used as a replacement for aged ML techniques in healthcare [10].

Addressing machine learning, the use of deep neural networks (DNN) has appeared to be of a desired interest, especially in radiology, for it is a branch of medicine primarily related to image diagnostics. Moreover, in computer-aided detection and diagnosis (CAD), machine learning methods are utilized to analyze data and make a certain assessment of the patient’s condition.

Deep learning uses distinct neural networks for discrete operations, i.e., for image, text and speech processing, etc. A convolutional neural network (CNN) is used for finding patterns in images, recognizing objects, categories, classes and can also be useful for recognition of audio and similar signal-data. A recurrent neural network (RNN) is mainly employed in natural language processing and speech recognition. Deep learning comes often as a combination with computer vision and natural speak recognition which are subfields of AI per se [11]. Expert systems belong to AI as its subcategory and are as such used for performing diagnostics and further analysis based on the collected data provided by electronic healthcare systems [12]. They can be also used for giving an accurate prognosis about a patient's disease, similar to aforementioned deep learning techniques that analyze pictures and predict the outcome. Expert systems are also, as almost every segment of AI, powered by neural networks, i.e., entirely machine learning/deep learning.

3.1. Radiologic Applications of ML/DL

Deep learning methodology has been presented as a well-tempered yardstick for image processing analysis whilst showing promising results in segmentation and registration. Of a special interest was application of CNN in solving the problem of medical imaging segmentation which include the approaches to the segmentation of tumors, lungs, biological cells and membranes, bone tissue, cell mitosis and tibial cartilage. In addition to performing such operations, two-dimensional convolutional neural networks were utilized [11]. The problem however occurs in patch-based methods which requires focusing on a certain part of the image and then re-processing it in the latter stage. The 2D-CNN method is considered to be rather impracticable for the described reason, wherefore fully convolutional neural nets or fCNN were introduced by Kang and Wang [13]. Their main advantage of fCNN is taking the image as a whole without patching it, whereby redundancies are minimized. However, fCNNs produce segmentations of lower quality compared to the input images. Therefore, Bosch et al. proposed a three-layer convolutional encoder network for multiple sclerosis lesion segmentation that is a combination of convolutional and deconvolutional layers which is allowing segments and input images to be of the equal quality. The aforementioned network can also be employed in fields of semantic segmentation and lesion localization (Figure 2).

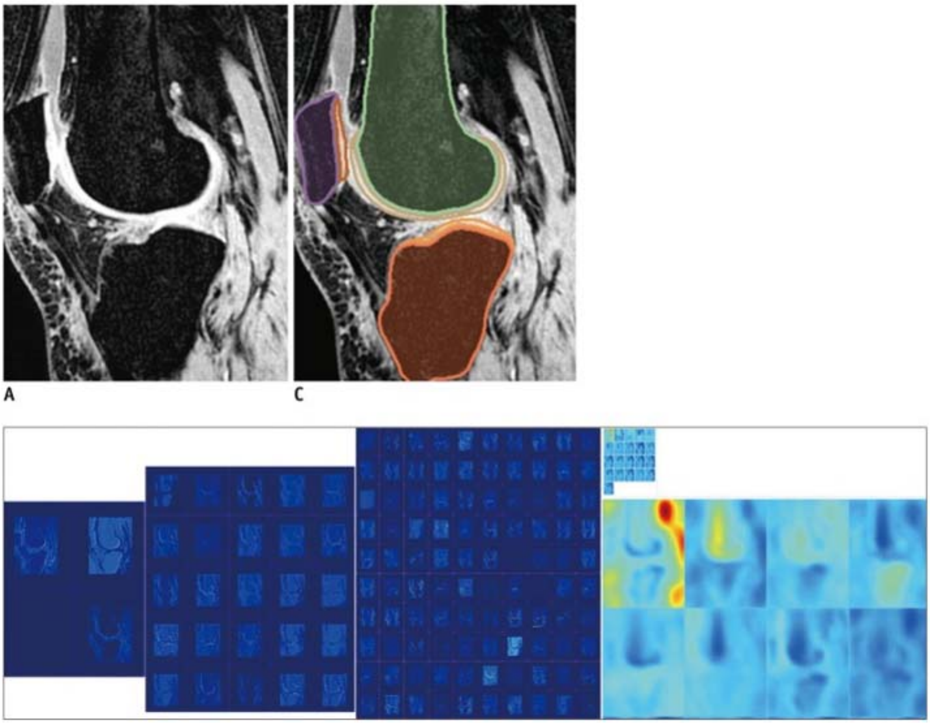

Figure 2.Semantic segmentation of a knee MRI (A – input image; B- response maps with different depths in fCNN; C – output result).

3.2. Computer-aided detection and diagnosis (CAD) in predictingillnesses

A computer-aided detection and diagnosis is a class of computer systems that aim to assist in the detection and/or diagnosis of diseases through a ‘’second opinion’’ [14]. Many different variations of CADs (Figure 3) have found its implementation as a part of picture archiving and communication systems (PACS).

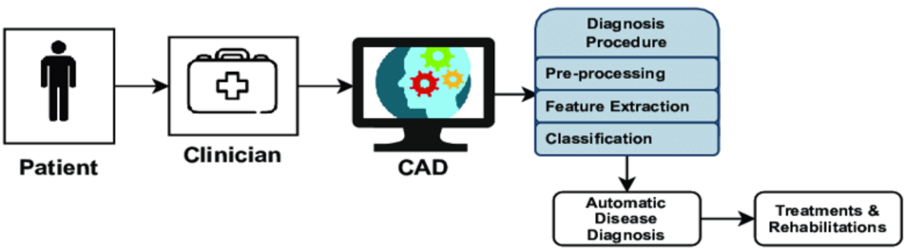

Figure 3. The diagram of functioning of CAD [15]

CAD consists primarily of two layers: detection and false positivity reduction. However, the current background of CAD attaches to it an epithet of the weak performance, since its sensitivity to imaging protocols and noise, reduces its presence in routine clinical practice to minimum. Applying deep learning techniques to CAD could be a definite solution on the path towards upgrading CADs. Recent studies of the deep learning-based CAD show a high accuracy in detecting breast and lung cancer as well as Alzheimer's disease. In addition, CAD systems are proposed for the early diagnosis of Alzheimer's disease based on fusion of anatomical (MRI) and functional (^{8}F-fluorodeoxyglucose positron emission tomography or FDG-PET) multimodal images [16].

3.3. Healthcare Virtual Assistants

AI virtual assistants, not only medical but also those for non-medical purposes, are powered by deep-learning algorithms that learn from the responses of people their communication is limited to. AI virtual healthcare assistants have myriad advantages, some of which are reduced waiting times, obtaining daily medical advices, practicability, anonymity and easing the pressure on doctors[17]. Recently, AI chatbots have shown therapeutic qualities which can be crucial for keeping the mental well-being of an individual.

One of the primary benefits of healthcare virtual assistants is their ability to provide personalized and on-demand support to patients. Patients can engage with virtual assistants through various channels such as voice commands or text-based interfaces, allowing them to access information, ask questions, and receive real-time assistance. Virtual assistants can offer guidance on symptoms, help with self-diagnosis, provide medication reminders, and offer general healthcare advice. By empowering patients with reliable and immediate information, virtual assistants contribute to patient education and enable individuals to make more informed decisions about their health.As healthcare virtual assistants continue to evolve, advancements in AI and NLP technologies are enabling them to become more sophisticated and capable of handling complex medical queries and interactions. They can integrate with electronic health records (EHRs) and other healthcare systems, ensuring seamless data exchange and enhancing clinical decision support. Additionally, virtual assistants can learn from patient interactions, continuously improving their performance and accuracy over time.

4. Robotics in Healthcare

Robotics in healthcare has emerged as a transformative field, revolutionizing the way medical procedures are performed, patient care is delivered, and healthcare professionals operate. By combining the power of robotics with advancements in artificial intelligence (AI) and precision engineering, robotic technologies have paved the way for significant improvements in diagnosis, surgery, rehabilitation, and patient assistance [18].

4.1. Robotics and AI in surgery

Robotics-assisted surgery is the name for the use of a mechanical device to assist surgery in place of a human-being or in a human-like way. There are three types of robotic systems used in surgery [19]:

- Active systems undertake pre-programmed tasks while remaining under the control of the operating surgeon;
- Semi-active systems allow a surgeon to complement the system's pre-programmed component;
- Master–slave systems lack any autonomous elements; they entirely depend on a surgeon's activity. In laparoscopic surgery or in teleoperation, the surgeon's hand movements are transmitted to surgical instruments, which reproduce them.

Surgeons can also be supported by navigation systems, which localize positions in space and help answer a surgeon's anatomical orientation questions. Real-time tracking of markers, realized in modern surgical navigation systems using a stereoscopic camera emitting infrared light, can determine the 3D position of prominent structures [20].

4.2. Rehabilitation and Robotics

Plethora of AI and robotic systems support rehabilitation tasks such as risk prevention, treatment and monitoring [21]. Fall detection systems use smart sensors which are supposed to alert the medical staff if the patient requires help. Built-in system powered by AI allows these systems to learn human behavioral patterns and characteristics over time. Robots can support patients in recovering motions after a stroke using exoskeletons [22], or recovering or supplementing lost function[23]. This means that a robot can be used to help the individual to train and recover motoric functionalities after a certain critical condition.

The use of proper rehabilitative procedures is essential for motor recovery in patients with conditions like brain injury, stroke, or chronic pain. Limb rehabilitation, especially upper and lower limb, is common but often requires trained healthcare professionals. Remote treatment using home-based medical devices has emerged as a suitable solution for accessibility challenges. Advanced technologies like robotics, machine learning, and IoT have been employed to provide rehabilitation. Examples include IoT-aided robotic devices,sensors for control, remote monitoring, and natural user interfaces. However, replicating the skills of physiotherapists and providing more complex therapies remain challenges. Integration of IoT technology allows observation, management of multiple patients, and personalized therapy suggestions. Future rehabilitation systems should focus on multi-modal approaches, such as the ROBIN rehabilitative robot [24]. Research explores augmented reality, video games, and play to enhance patient engagement and motor function. However, the high cost of rehabilitation robots and limited access to supervised environments hinder their widespread adoption. Efforts should be made to develop low-cost systems suitable for unsupervised settings, with adaptability to tailor therapy routines based on patient progress [18].

4.3. Robotics and AI for Telemedicine

Robotics and artificial intelligence (AI) are playing increasingly significant roles in advancing telemedicine [25], the practice of delivering healthcare remotely. These technologies are transforming the way healthcare is provided, enabling more efficient, accurate, and accessible care for patients worldwide.

Robotic systems are being integrated into telemedicine to facilitate remote examinations, diagnostics, and even surgeries. Tele-robotic systems allow healthcare professionals to remotely control robotic devices equipped with cameras, sensors, and specialized instruments to examine patients in real-time. This enables experts located at a different location to perform procedures and make informed medical decisions. For example, a surgeon in one location can remotely operate a surgical robot to perform minimally invasive surgeries on a patient located miles away. This technology extends specialized medical expertise to underserved areas, reduces travel requirements for patients, and enhances access to high-quality care [26].

AI-driven technologies are also revolutionizing telemedicine by augmenting medical decision-making, improving diagnostics, and enhancing patient monitoring. AI algorithms can analyze vast amounts of patient data, including medical records, imaging scans, and patient-reported symptoms, to assist healthcare providers in making accurate diagnoses and treatment recommendations [27]. AI-powered diagnostic systems can quickly and accurately interpret medical images, such as X-rays or CT scans, aiding radiologists and reducing the time needed for diagnosis. Additionally, AI-based chatbots and virtual assistants can interact with patients, gather information about their symptoms, and provide preliminary assessments or guidance on appropriate care options.

The combination of robotics and AI in telemedicine holds immense potential for remote patient monitoring. Connected devices, wearable sensors, and remote monitoring systems can collect real-time patient data, such as vital signs, activity levels, and medication adherence, and transmit it to healthcare providers. AI algorithms can analyze this data for early detection of health issues, flagging any abnormalities or changes that may require medical intervention. Remote patient monitoring powered by robotics and AI enables proactive care management, early intervention, and improved patient outcomes, particularly for individuals with chronic conditions who need continuous monitoring and timely medical attention.

Systems supporting telemedicine support, among others, the triage, diagnostic, non-surgical treatment, surgical treatment, consultation, monitoring, or provision of specialty care [28].

- Medical triage assesses current symptoms, signs, and test results to determine the severity of a patient's condition and the treatment priority. An increasing number of mobile health applications based on AI are used for diagnosis or treatment optimization [29]
- Utilization of IoT technologies and inserting smart and wearable devices into quasi smart homes; they are meant for collecting data from patients and helping in everyday life [30].
- Telemedicine for specialty care is designed for tracking the patient's mood and things related to mental health; such devices tend to attempt to socialize emotionally detached and socially isolated patients in order to reduce anxiety, depression and similar mood disorders [31].
- ASUS Zenbo Bot is a robot specially designed for children for treating ADHD, autism and similar attention disorders [32].
- Robot DE NIRO is similarly designed to interact safely and friendly with humans in order to promote socialization [33].

4.4. Robotics and AI for Prediction and Precision Medicine

Prediction and precision medicine aim to provide individualized healthcare solutions by considering various factors, including genomic variations, lifestyle factors, environmental influences, and demographic characteristics. By leveraging robotics and AI, healthcare professionals can harness the vast amount of available data and apply advanced algorithms to predict disease risks, identify early warning signs, and tailor interventions accordingly [34].

Furthermore, precision medicine relies on the integration of multiple data sources and the application of sophisticated algorithms to deliver targeted and personalized treatment plans. Robotics and AI play a crucial role in this process by providing comprehensive analysis and interpretation of patient data. AI algorithms can detect subtle patterns and trends in patient health records, genetic profiles, and treatment outcomes, helping healthcare professionals make more informed decisions about treatment strategies. By considering individual variations and optimizing treatment plans based on precise patient characteristics, precision medicine aims to improve treatment outcomes, minimize adverse effects, and enhance patient satisfaction.

4.5. Natural Language Processing in Healthcare

Natural Language Processing (NLP) is a field of Artificial Intelligence (AI) that enables machines to understand and communicate in natural language, like humans do. This subcategory of AI is also powered by machine learning/deep learning techniques, for the large datasets are to be dealt with (Figure 4). Healthcare natural language processing uses specialized engines capable of scrubbing large sets of unstructured data to discover previously missed or improperly coded patient conditions. This helps to uncover the disease which was not previously coded, i.e., it is being pointed to hidden patterns in order to maintain a high-quality AI-powered healthcare [35].

NLP negation is another process which helps doctors to identify the absence of certain symptoms. AI recognizes the keywords such as ''unlikely'', ''not present'', etc. For example, NLP may analyze the phrases and say whether the patient has breast cancer for instance. Therefore, the system must be familiar with the medical natural language and know all forms of negation in one's language.

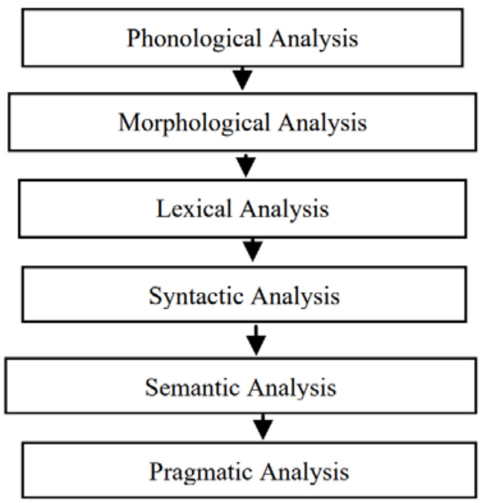

Figure 4.Levels of NLP in Healthcare

5. Conclusion

Based on a comprehensive overview of the progress in AI technology over the years and the extensive efforts invested in its development and enhancement, it can be inferred that this field is poised for continuous advancement and is expected to give rise to a multitude of new technologies, particularly in the realm of medicine. The evolution of medical technology, spanning from advancements in optics to electromagnetism, has now encompassed artificial intelligence, enabling the medical profession to significantly improve patient outcomes and save countless lives.

The application of AI in medicine extends across various domains, ranging from leveraging collected data for accurate diagnosis and prognosis to actively assisting in surgical procedures, aiding patient recovery, and more. This technology has transformed the medical landscape by making complex procedures more precise and efficient, enhancing medical decision-making, and streamlining patient care. For instance, laser technology and corrective lenses have restored normal vision to millions of individuals, while electrically powered medical devices have facilitated improved motor function and increased life expectancy. AI has further revolutionized cognitive functioning, providing invaluable assistance in medical research, data analysis, and decision support systems.

Although it is true that access to AI in healthcare may be limited in some developing countries, the undeniable benefits it brings to medical practice will inevitably propel its widespread adoption and accessibility. As the field progresses, it is foreseeable that virtual medical assistants and similar applications will become indispensable tools, transcending geographical barriers and empowering healthcare professionals worldwide. The ultimate goal is to ensure that the advantages and advancements brought forth by AI are universally available, promoting equitable healthcare outcomes on a global scale.

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LIST OF AUTHORS

Arslanagić Haris
University of Sarajevo
School of Economics and Business
Trg oslobođenja 1
71000 Sarajevo, Bosnia and Herzegovina

Avdagić-Golub Elma
University of Sarajevo
Faculty of Traffic and Communications
Zmaja od Bosne 8
71000 Sarajevo, Bosnia and Herzegovina

Banjanović-Mehmedović Lejla
University of Tuzla
Faculty of Electrical Engineering
Dr. Tihomila Markovića 1
75000 Tuzla, Bosnia and Hezegovina

BratovcicAmra
University of Tuzla,
Faculty of Technology
UrfetaVejzagića 8
75000 Tuzla, Bosnia and Hezegovina

Bičo Ćar Mirha
University of Sarajevo
School of Economics and Business
Trg oslobođenja 1
71000 Sarajevo, Bosnia and Herzegovina

Čičak Mirjana
Mechanical Engineering Faculty
University of Slavonski Brod
Croatia

Dreković Edisa
University of Niš
Faculty of Economics
Serbia

Eljazović Maida
Nelt Ltd.
East Sarajevo
Bosnia and Herzegovina

Gurbeta Pokvić Lejla
Verlab Research Institute, Sarajevo
Bosnia and Herzegovina

Husak Ermin
University of Bihać
Technical Faculty
Irfana Ljubijankića
77000 Bihać, Bosnia and Hezegovina

Husaković Anel
Eacon Zenica
Bosnia and Herzegovina

Imamović Elma
Verlab Research Institute, Sarajevo
Bosnia and Herzegovina

Karabegović Edina
University of Bihać
Technical Faculty
Irfana Ljubijankića
77000 Bihać, Bosnia and Hezegovina

Karabegović Isak
Academy of Sciences and Arts
of Bosnia and Herzegovina
Bistrik 7, Sarajevo
71000 Sarajevo, Bosnia and Hezegovina

Kosovac Amel
University of Sarajevo
Faculty of Transport and Communications
Zmaja od Bosne 8
71000 Sarajevo, Bosnia and Herzegovina

Lemeš Samir
University of Zenica
Polytechnic Faculty
Fakultetska 1
72000 Zenica, Bosnia and Herzegovina

Lovrec Darko
University of Maribor
Faculty of mechanical engineering
SI 2000 Maribor, Slovenia

Mahmić Mehmed
University of Bihać
Technical Faculty
Irfana Ljubijankića
77000 Bihać, Bosnia and Hezegovina

Majstorović D. Vidosav
University of Belgrade
Faculty of Mechanical Engineering
11000 Belgrade, Serbia

Malisa Viktorijo
AUVA Allgemeine
Unfallversicherungsanstalt
Vienna, Austria

Milošević Miodrag
University of Novi Sad,
Faculty of Technical Sciences,
Novi Sad, Serbia

Mitrović Radivoje
University of Belgrade
Faculty of Mechanical Engineering
11000 Belgrade, Serbia

Mitrović Žarko
University of Belgrade
Faculty of Mechanical Engineering
11000 Belgrade, Serbia

Mrđanović Emina
Verlab Research Institute
Sarajevo
Bosnia and Herzegovina

Muminović J. Adis
University of Sarajevo
Faculty of Mechanical Engineering
Vilsonovo šetalište 9
71000 Sarajevo, Bosnia and Hezegovina

Pervan Nedim
University of Sarajevo
Faculty of Mechanical Engineering
Vilsonovo šetalište 9
71000 Sarajevo, Bosnia and Hezegovina

Smajić Jasmin
Protodevs Sarajevo, Vilsonovo šetalište no.9, 71 000 Sarajevo, Bosnia and Herzegovina

Softić Adna
Verlab Research Institute,
Sarajevo, Bosnia and Herzegovina

Stojić Nikola
Schindler Management Ltd.
Switzerland

Stupar Savo
University of Sarajevo
School of Economics and Business
Trg oslobođenja 1
71000 Sarajevo, Bosnia and Herzegovina

Šahić Elvir
University of Sarajevo
School of Economics and Business
Trg oslobođenja 1
71000 Sarajevo, Bosnia and Herzegovina

Šarić Isad
University of Sarajevo
Faculty of Mechanical Engineering
Vilsonovo setaliste no. 9
71 000Sarajevo, Bosnia and Herzegovina

Šestić Munira
University of Sarajevo
School of Economics and Business
Trg oslobođenja 1
71000 Sarajevo, Bosnia and Herzegovina

Zeba Gordana
Mechanical Engineering Faculty
University of Slavonski Brod
Croatia

CO-ORGANIZERS - CONFERENCE PARTNERS

MINISTRY OF ENERGY, MINING AND INDUSTRY OF THE FEDERATION BOSNIA AND HERZEGOVINA
https://fmeri.gov.ba/

ROBOTICS SOCIETY IN BOSNIA AND HERZEGOVINA
http://www.robotika.ba/

FOREIGN TRADE CHAMBER BOSNIA AND HERZEGOVINA
https://www.komorabih.ba/

CHAMBER OF ECONOMY OF THE FEDERATION OF BOSNIAI AND HERZEGOVINE
www.kfbih.com

INTERNATIONAL ASSOCIATION FOR TECHNOLOGICAL DEVELOPMENT AND INNOVATIONS UKRAINA
http://iatdi.org/

TECHNOLOGY PARK INTERA MOSTAR BOSNIA AND HERZEGOVINA
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