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Digital technologies as an essential part of smart factories and their impact on productivity

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Abstract. Industry 4.0 has led to the emergence of various digital technologies. To keep pace with the digital transformation, manufacturing companies must adapt to the new conditions imposed by the business market and increasingly strive to implement so-called smart factories. This paper points out the most common digital technologies related to the management of manufacturing systems. In addition to identification, a systematic literature review was conducted to investigate their impact on increasing productivity. Results indicate that a significant increase in the number of research began in 2015 and is experiencing its greatest expansion in 2018. Important methodologies observed during the literature analysis are a systematic review of the literature for the largest number of theoretically oriented papers, and case studies, practical models for the minority that make up the practice-oriented papers. Also, 68 percent of papers focus more on the theoretical than on the practical implications, and 72 papers indicate a direct link between productivity and digital technologies used in the digital transformation and implementation of smart factories.

Keywords: Industry 4.0, Digital Technologies, Smart factory, Productivity.

1 Introduction

In today's manufacturing landscape, traditionally oriented companies are facing numerous challenges like high competition and globalization. These challenges are forcing companies to constantly change, innovate, and digitize. What is driving companies into the so-called Fourth Industrial Revolution, known as Industry 4.0, is the need for automated, more efficient processes, as well as faster delivery times [1]. Identification of trends that are current in industrial automation and include new production technologies that increase productivity and production quality is attributed to Industry 4.0.

The widespread use of interdependent digital technologies and the rise of cyber-physical spaces or smart factories are common to Industry 4.0. [2]. To achieve sustainability and further develop their businesses, manufacturing companies need to find an appropriate response to the frequent changes in customer demands, development of new technologies, and dynamic competition [3]. To prepare for the decline in added value in the manufacturing

industry and improve productivity, the manufacturing sector is now working on process innovation, i.e. smart factories [4], [5].

Given that digital technologies are an integral part of smart factories and are increasingly represented, this paper intends to shed the light on their domain by answering the following research questions:

1. What are the key technologies in the digital transformation of manufacturing companies?
2. What impact do digital technologies have on the productivity of smart factories?

The paper's structure is as follows: section two describes the methodology in detail, followed by the description of identified digital technologies. Section four presents their impact on the productivity of smart factories, followed by a discussion in section five. Finally, the paper is concluded in section six.

2 Research methodology

A characteristic that is the essence of academic research is the review of literature because knowledge is improved and built on previously existing work. Insight into previously existing work helps us to move the border of knowledge, pointing out where that border is. To understand the true breadth and depth of existing work and be able to identify shortcomings that need to be explored, a systematic literature review of the relevant literature is needed. By analyzing and grouping related literature, we can find answers to the above-stated two research questions. In addition, there is an opportunity to use the criteria to identify certain weaknesses and inconsistencies of existing work, as well as its quality [6]. Some of the perceived advantages of the systematic literature review method are reflected in the summarization of previous work, identifying what has been achieved and gaps if any, and avoiding duplication [7]. A successful systematic literature review includes three main phases: review planning, review implementation, and review reporting [8]. Given this, a systematic literature review was conducted by identifying and selecting primary studies, extracting, analyzing, and synthesizing data. The systematic literature review presented in this article follows the principles of deductive reasoning and aims to answer a particular research question. When analyzing the literature, it was noticed that significant growth of research conducted on this topic began in 2015, and the greatest expansion is experienced in 2018.

Online databases, Scopus and Web of Science were used to find and analyze the literature, these specific index bases were selected because of their reliability and a large number of papers for analysis. The keyword string and the systematic review process are presented in figure 1. By the initial search, 171 articles were obtained, while after the abstract analysis, this number was reduced to 136. After noticing repetitions and overlaps, relating to the occurrence of the same papers on both bases, 87 articles were selected for the final analysis.

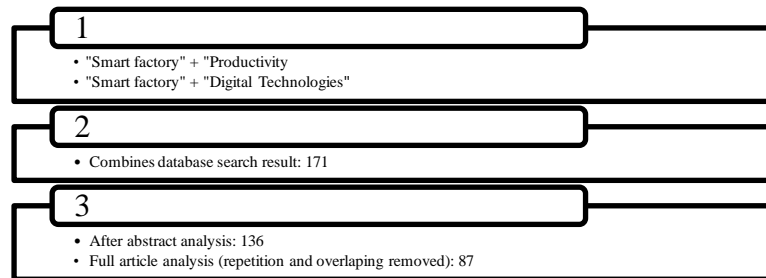


Figure 1. Overview of the systematic literature review process

3 Digital transformation technologies

Industry 4.0 implies the transformation of industrial production into smart production. What has been considered the driving force of this transformation is the advanced development of digital technologies that make up the trend of Industry 4.0. What is crucial about these digital technologies is their integration and efficient use in data-driven production in such a way as to create value and meaningful information [9] [10]. The ubiquitous, massive use of interdependent digital technologies forms the basis of Industry 4.0. In this sense, smart factories represent a cyber-physical space in which production processes involve machine-machine and human-machine interactions and in which various objects are transformed into mutually communicating intelligent systems [2], [11]. The use of digital technologies enables companies to save costs by helping them optimize the waste of materials and inventory. Thanks to remote cooperation, the cooperation of employees who are on the spot and outside are significantly facilitated. Digital technologies help them keep up to date with information and reduce communication gaps. The merging of information and operational technology has brought new digital solutions such as additive manufacturing, advanced robotics, augmented and virtual reality, big data, cloud computing, and the Internet of Things (IoT) creating a cyber-physical environment. Figure 2 shows the previously listed digital technologies identified during the literature review, related to production management. By applying the mentioned additive manufacturing, significant progress is made in processes such as research and development. Industry 4.0 with its rapid advances in digital transformation and digital technologies can make an impact on entire manufacturing systems, through technologies such as IoT and Artificial Intelligence (AI). The digital transformation in the manufacturing sector is caused precisely by the integration of these technologies with previous processes and systems across the value chain [12], [13].

By a detailed analysis of 87 papers, it is possible to see what is the trend in digital technology research in the context of the smart factory. A significant increase in the number of research began in 2015 and is experiencing its greatest expansion in 2018. The largest percentage of papers (68%) focus more on the theoretical than on the practical implications of this topic. What they have in common is that they point out the possibilities provided by the above-mentioned digital technologies. What is also noticeable are the dominant areas that deal with this topic, and those are Engineering and Computer Science.

A closer, individual explanation of the identified digital technologies belonging to the Industry 4.0 concept will be given below.

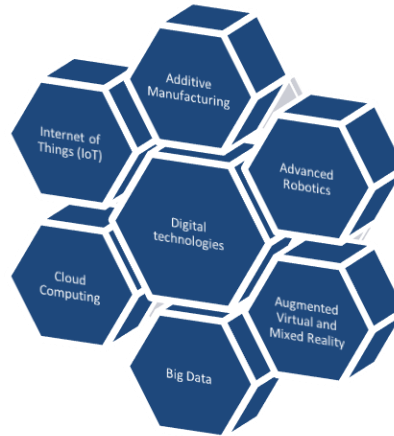


Figure 2. Digital technologies related to manufacturing system management

3.1 Additive Manufacturing

Additive Manufacturing is a process used for creating complex structures using Computer-Aided Design (CAD) data. It has caused the time and expense of design to decrease. With this 3-D printing process, items can be personalized to a broader degree. Additive Manufacturing's worldwide, industry revenue is continuously increasing. It provides major advancements in the research and development process [1], [12].

3.2 Advanced Robotics

Robots have been an essential part of the manufacturing sector for a very long time. In Industry 4.0, robots are no longer tools that were used by humans. Instead, they are independent, self-governing, and intelligent machines integral to work units. There have been numerous improvements compared to traditional robots. Due to these improvements, the tasks have become much more economical than earlier [12].

3.3 Augmented Virtual and Mixed Reality

These technologies have made it possible for the business to provide personalized product design, a dedicated manufacturing process, and individual after-sales service. **Augmented Reality:** Instead of fully providing a virtual experience, this technology enhances the real-world experience with pictures, text, and other virtual data with smartphones, smart lenses, AR glasses, etc. **Virtual Reality:** This technology enables the user to feel that they are moving in a virtual surrounding. It uses a VR headset that is connected to a PC or a console. **Mixed Reality:** This technology is a step beyond AR. The user needs to wear an MR headset to experience mixed reality, which offers a holographic experience through the translucent glass. Using MR, virtual objects placed in the real world respond like real objects. To be summed up, it is a combination of gesture, gaze, and voice recognition technology with a motion controller that helps deliver the MR experience [12] [14].

3.4 Big Data

The advanced sensors, actuators, and processes produce a large amount of industrial data [14]. As the word says, big data means a massive amount of data increasing exponentially with time. It uses software that consolidates data mining, data storage, and data visualization. The comprehensive term embraces data, and data framework, including tools and techniques used to investigate and transform data [12], [15].

3.5 Cloud Computing

Cloud Computing (CC) is revolutionizing IT environments in most fields of the economy. Its service-based approach enables collaboration and data exchange on a higher level, with better efficiency and parallel decreasing costs. Also, manufacturing environments can benefit from cloud technology and better fulfill fast changes in market demands, by applying diverse cloud deployment models and by virtualizing manufacturing processes and assets into services [12]. CC is in general an IT architectural model where computing services (both hardware and software) are abstracted and delivered to customers over the Internet, on-demand, in a self-service fashion, independent of device and location. The Cloud model embodies unique characteristics and can have various service and deployment models: while service models are typically an end-user's perspective in the CC industry, different delivery models refer to different layers of the CC architecture [16]. For example, Kehoe [17] pointed out how CC influences system improvement by providing access to datasets, models, publications, simulation tools and benchmarks, public calls for projects and systems, and open-source software.

3.6 Internet of Things

The Internet of Things is a network of physical objects that use sensors, software, and other smart devices to transfer and receive data from other systems over the internet. It has endless business or personal possibilities. Industrial applications of IoT are extensible and customizable. It has various prebuilt applications for fraud detection, predictive maintenance, and Supply network optimization. Advanced analytics platforms such as IoT platforms can extract data from multiple types of sources such as applications, sensors, devices, files, etc. via connectors and facilitate complex analysis including what-if analysis. This in turn provides valuable insights that help improve efficiency, reduce costs and achieve optimization [12], [18], [19].

4 Impact of digital technologies on smart factory productivity

Mechanization, electricity, and information technology have caused a large increase in productivity during the previous three industrial revolutions. The core technology for Industry 4.0 consists of Cyber-Physical Systems (CPS), which by making production systems changeable and modular enable mass production of highly customized products. Communicating over the IoT, CPS connects goals, machines, infrastructure, processes, and people, enabling the integration of the physical and virtual worlds [1]. The very concept of CPS is shown in Figure 3. Technological revolutions, such as Industry 4.0, which include new paradigms of IoT and CPS for analysis, monitoring, and overall process automation, are transforming production and logistics processes by creating smart factories, intending to increase

efficiency and productivity. In this context, the basis of industrial IoT consists of wireless sensors that are used to detect irregularities such as downtime, optimize efficiency and increase productivity in real-time. These wireless sensor networks are much more flexible and cost-effective to install and allow faster integration into existing industrial production networks [20]. New digital technologies, as part of the Industry 4.0 concept, point to the possibility of achieving flexibility and superior productivity at the same time [21].

Authors such as Wang [22] present a framework that includes three elements, industrial wireless networks, CC, and fixed or mobile terminals with smart artifacts such as products, machines, and conveyors. Such ecosystems can self-organize with the help of feedback from the big data analytics blocks working in the cloud. Based on this, it was concluded that self-organization, coordination, and feedback are what provide communication between products and smart machines to be tuned for flexible and productive production of multiple product types.

The largest number of analyzed papers, as many as 72 papers, indicate a direct link between productivity and digital technologies used in the digital transformation and implementation of smart factories. Almost all of these isolated studies imply that digital technologies have a positive impact on the productivity of manufacturing companies. The productivity of smart manufacturing systems is undoubtedly very closely related to the application of digital technologies shown in Figure 2.



Figure 3. The concept of cyber-physical systems

5 Discussion

An analysis of the existing literature has identified that certain digital technologies have a positive impact on the productivity of smart factories. Such a positive impact is made possible by the realization of the benefits of implementing digital technologies, and they are directly related to productivity. This means that the connection between these two variables is still of the indirect type. That is, some of the main advantages of the application of digital technologies are the reduction of labor costs, energy and time savings, better health and safety of employees, big data management, and more efficient supply chains. All of the above further leads to increased productivity as well as increased revenue and profits.

What is important is the role of man in such a system. Certain mistakes as a result of the human factor can lead to impaired productivity, while on the other hand, a quality operator can significantly contribute to that productivity. Therefore, the issue of training and retraining employees in smart factories arises. For digital technologies to reach their full potential

and full impact on productivity, in addition to their introduction, it is necessary to pay attention to people, not just technology.

Although it may be a risky and difficult undertaking, the development and transition to smart factories bring many benefits. If the company successfully implements a smart factory, it will achieve significant savings, while increasing the quality of the product, shortening its market entry, and increasing sales. The implementation of a smart factory enables significant growth in flexibility, productivity, and profitability. To reap all these benefits of a smart factory, companies must adhere to three basic principles: cultivate digital people, introduce agile processes, and configure digital, modular technologies for production optimization [5], [18]. These three principles represent the challenges that manufacturing companies face when they decide to implement the smart factory concept.

However, when analyzing the literature, a large omission was noticed, which exists and is not negligible, and that is that the works mostly deal only with theoretical knowledge, while the great lack of application of this knowledge in practice, on real examples, which needs to change in the future for as much knowledge as possible to be supported by facts and therefore relevant.

6 Conclusion

This paper identifies digital technologies that are applied in smart factories and have an impact on productivity. These technologies are presented individually and their positive impact on productivity is explained, through the action on various business indicators, which achieved an answer to research questions but also identified research directions that are not covered. Results indicate that a significant increase in the number of research began in 2015 and is experiencing its greatest expansion in 2018. Also, 68 percent of papers focus more on the theoretical than on the practical implications, and 72 papers indicate a direct link between productivity and digital technologies used in the digital transformation and implementation of smart factories.

The limitation of this paper is related to the principles listed in the previous chapter and first refers to the potential problems in the acceptance of digital technologies by employees in manufacturing companies. Digital technologies, although to some extent autonomous, require the presence of humans, so it is very important to observe this factor as well. The second limitation concerns the possible mismatch of infrastructure, machinery, and process structure, which requires adaptation and also like the previous limitation, maybe the direction of future research. The third limitation, which is perhaps the biggest problem in the implementation of digital technologies, is data protection. This paper does not cover measures implemented to enable data protection and should be included in research in the future.

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