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PILLARS OF THE INDUSTRY 5.0 USED IN INDUSTRIAL ENGINEERING

BY

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Abstract. This paper aims to highlight the development potential and impact of the I5.0 pillars and their implications in industrial sectors affecting the manufacturing process. It examines the perspective through the lens of the three principles proposed by I5.0: human-centric, sustainability and resilience, which outline these new manufacturing technologies used to improve production processes in most fields, including industrial engineering. The pillars of the I5.0 concept identified in this paper will describe the amplification of this digital transformation and the more meaningful and effective collaboration between humans and machines and systems in their digital ecosystem. It is therefore important to note that, regardless of how the I5.0 concept is defined, these pillars underpin a new industrial revolution and define a new level of organisation and control over the future entire product life cycle value chain.

Keywords: Industry 5.0, Pillars, Additive Manufacturing, Collaborative Robots, Augmented Reality, Artificial Intelligence.

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1. Introduction

The evolution of industry through Industry 5.0 is predicated upon a greater collaboration between humans and machines. This is in contrast to the preceding Industry 4.0 technologies, which were primarily focused on the integration of automation and digitalization within manufacturing. Industry 5.0 represents a shift towards more holistic approaches to industry development.

Consequently, Industry 5.0, through the nine pillars of Industry 4.0, represents an effort to expand and place human creativity and well-being at the center of industry. This is achieved by combining the speed, reliability and performance of machine technologies with human ingenuity and talent. In conclusion, it can be stated that Industry 5.0, through its fundamental pillars in industrial engineering, places human needs and interests in the center of the process, thus achieving a human-centred industry. Furthermore, it helps businesses to reduce their environmental impact through process development, creating a sustainable industry. Finally, it lays the foundations for a resilient industry that is able to support critical infrastructure in times of crisis.

2. Aspects of knowledge and research on Industry 5.0

History. The concept of Industry 4.0 was first introduced in 2011 at the Hannover Technology Fair by a team from the German Federal Ministry of Education and Research (BMBF) and was referred as the 4th Industrial Revolution or Digital Industrial Revolution. This concept involved the use of smart technology in automating manufacturing processes and practices in manufacturing industry. In contrast, the concept of Industry 5.0 was initially promoted by academia starting in 2017. Subsequently, in 2021, the European Commission introduced the term Industry 5.0 (Industry 5.0) into official discourse following discussions between participants from research and technology organisations and funding agencies across Europe. In two virtual workshops organised by the "Prosperity Directorate" of the Directorate-General for Research and Innovation on 2 and 9 July 2020, the document "Industry 5.0" was officially published. On 4 January 2021, the European Commission published the document "Towards a Sustainable, Human-centric, and Resilient European Industry" (Xu *et al.*, 2021).

Definition. The advent of Industry 5.0 is the consequence of the beneficial and detrimental effects of related concepts, including Industry 4.0, Society 5.0 and Operator 5.0 (Leng *et al.*, 2022).

Nevertheless, Industry 5.0 has not yet evolved to the same extent as Industry 4.0. Consequently, numerous industry specialists and researchers have offered various definitions of Industry 5.0, some of which are presented below. One of the first definitions was offered by Michael Rada, the founder of this concept, who defines Industry 5.0 as a first human-driven industrial evolution based on the 6R principles (Recognize, Reconsider, Realize, Reduce, Reuse and Recycle) of industrial recycling. This is a systematic waste prevention technique and logistically efficient design to enhance the value of standard of living, innovative creations and the production of high-quality customized products.

Building on the concept of Industry 5.0, which acknowledges the potential of industry to contribute to social goals beyond employment and economic growth, namely to become a thriving supplier, to align production with the existing limits of the moment and to prioritise the well-being of the industrial worker, we can define Industry 5.0 as a concept that aims to reintroduce the lost dimension of a "human/value-centred Industry 4.0" (Tavares *et al*., 2022).

A similar lack of a concrete definition is evident in the Industry 4.0 concept. Many authors consider that, despite the considerable interest in this concept, there is no officially accepted definition for it, and that there is a lack of agreement on classification in the literature (Rajab *et al*., 2022). This has the effect of imposing significant limitations on the construction of theoretical frameworks and the comparability of research findings. In all governmental initiatives, practical, academic reports, studies, and partially overlapping concepts and terminologies have been used. Different labels have been employed to describe the phenomenon, including "Industrial Internet", "Industrial Revolution", "Smart Manufacturing" and later "Industry 4.0”. This term eventually became the most widespread, attracting exponential interest from researchers in technical and managerial disciplines.

It is of the utmost importance to comprehend the potential of Industry 4.0 and Industry 5.0 concepts and their implications in industrial sectors that affect the manufacturing process, supply chain and customer expectations. Regardless of how the Industry 5.0 concept is defined, it is important to specify that it represents a new industrial revolution that defines a new level of organisation and control over the entire value chain of the product life cycle. This revolution is oriented towards increasingly individualized customer requirements.

Features and principles. The Industry 4.0 concept proposes several design principles, shown in Fig. 1, that have been identified as accepted by the majority of authors in the literature. These include interconnection (interconnection or interoperability), virtualisation, decentralised decisions, real-time capability, service orientation, and flexibility (modularity) (Dikhanbayeva *et al*., 2020).

"The White Paper on Industry 5.0" published by the EU stated that Industry 5.0 has three characteristics: human-centredness, sustainability and resilience (Leng *et al*., 2022). These are illustrated in Fig. 2.

The human-centred approach prioritises the basic human needs and interests throughout the production process, moving from a technology-driven approach to a technological progress approach to a fully human and society-centred perspective (Leng *et al.*, 2022).

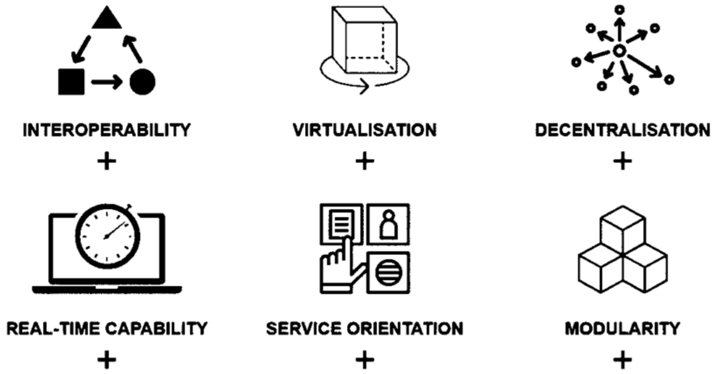

Fig. 1 – Industry 4.0 - Principles.

The economic aspect of sustainability is still expected to be a significant factor in the restructuring of technologies in the realisation of the Industry 5.0 vision.

Fig. 2 – Industry 5.0 - Main features (Mourtzis *et al.*, 2022).

The sustainable implementation of Industry 5.0 necessitates the timely adjustment of the common factor of the three pillars to optimise the overall construction of Industry 5.0. This entails the realisation of greater quantity, higher speed, better quality and cost savings.

The term resilience is used to describe the capacity of a system to maintain stability or to rapidly return to a state of equilibrium following a significant disruption, whether caused by political or natural factors. Such events could include the global pandemic of 2020, or other crises that place significant pressure on a system.

In light of the growing demand for personalisation among consumers, it is becoming increasingly evident that humans cannot be replaced by machines or robots in the industrial sector (Leng *et al*., 2022). Consequently, no automation or digitisation can be achieved without the involvement of humans, who bring additional fault-tolerance capabilities to the system. In Industry 5.0, the "human operator" is placed at the core of production systems (Leng *et al*., 2022).

Starting from the core definition of the Industry 5.0 concept based on the three characteristics above, Industry 5.0 associates three key systemic principles, each of which is focused on specific targets (Breque *et al*., 2021):

- Waste and pollution disposal design.
- Keeping products and materials in production and circulation.
- Regenerating natural systems and reducing carbon emissions (Breque *et al*., 2021).

However, both Industry 5.0 and Industry 4.0 have varying degrees of conceptual improvement in terms of revolutionising the way industries operate (Leng *et al*., 2022).

3. Pillars of Industry 5.0 used in Industrial Engineering

The fourth industrial revolution is defined by nine key elements/pillars, which are considered to be fundamental to Industry 4.0.

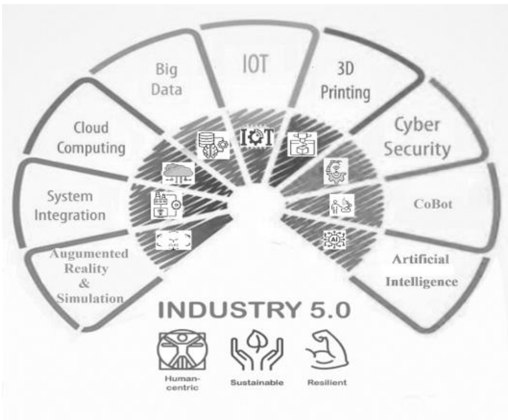

Fig. 3 – Pillars of Industry 5.0 (Vaidya *et al*., 2018).

These elements facilitate the integration of digital and physical systems, enabling the creation of autonomous and intelligent systems.

Industry 5.0 proposes to enhance the collaboration between humans and robots, placing human creativity and well-being at the centre of industry. This approach aims to enhance the efficiency of machine technologies in conjunction with human skills and abilities.

The following sections present an overview of new manufacturing technologies, their applications, and the potential for improving production processes in a variety of areas (Kumar *et al*., 2020). These include, but are not limited to, the field of industrial engineering, where such technologies are particularly relevant.

The Pillars of Industry 5.0, illustrated in Fig. 3., that are specific to Industrial Engineering domain can be summarised in four main components which are as follows:

- Additive manufacturing (3D Printing)
- Collaborative robots (CoBots)
- Simulation and Augmented Reality
- Artificial Intelligence

Also due to the development of the IT infrastructure, which allows industry to adopt it quickly and efficiently, Industry 4.0 also defines the major components, as illustrated in Fig. 3, used in this respect and whose role is to integrate a wide range of new technologies within the main components to create value:

- Cyber physical systems
- Internet of Things
- Big Data
- Cloud computing

However, the entire current production process will be transformed in this new technological model (Industry 4.0) with the help of a major form of integration, namely a component of horizontal integration and vertical integration (Perez-Lara *et al*., 2018).

3.1. Additive manufacturing

Additive manufacturing (3D printing) is a layered printing technology process that was invented in 1987. It employs the principle of layer-by-layer integration of materials. This technology generates a tangible object that replicates either the three-dimensional digital model of the object or the three-dimensional model of the object created in CAD software by depositing the constituent material in a layered manner using a computer-controlled processing tool (Ashima *et al*., 2021). In summary, additive manufacturing can be defined as a computer-aided process of forming a three-dimensional solid object of any shape by the superposition of successive layers of material.

The construction of material layers in additive manufacturing processes is achieved through a variety of techniques. Some processes utilise thermal energy from laser or electron beams, which are directed through optics to melt or sinter metal or plastic powder (Prakash *et al.*, 2018). In other processes, inkjet printheads are employed to spray binder or solvent onto ceramic or polymer powder with great precision (Prakash *et al.*, 2018). The principal additive manufacturing (AM) processes are illustrated in the following figure.

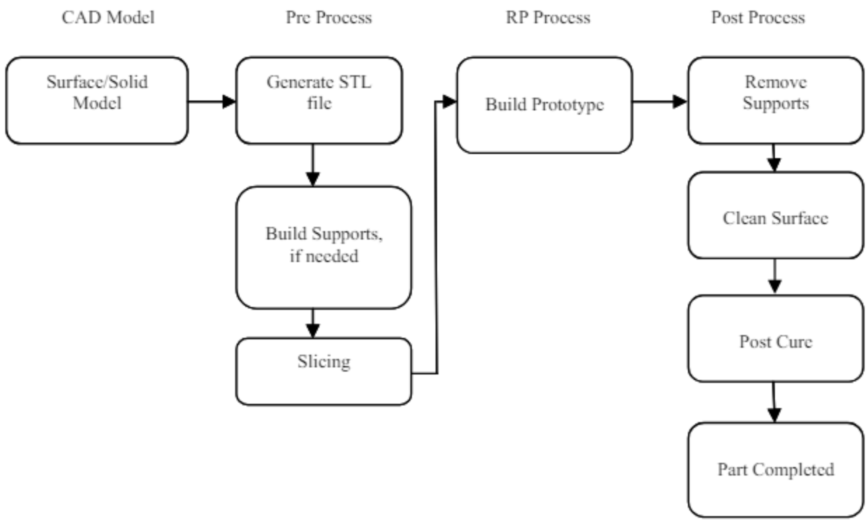

Fig. 4 – Process model for rapid prototyping (Prakash *et al.*, 2018).

According to ASTM (American Society for Testing and Materials), Additive Manufacturing has been divided into seven processes that include (Jandyal *et al.*, 2021):

- VAT photomicropolymerisation - includes prototyping technologies such as stereolithography (SLA), digital light exposure (DLP, CDLP);
- Material sputtering - includes material sputtering, nanoparticle sputtering, by material dosing (DOD);
- Binder jetting (BJ);
- Material extrusion - Thermoplastic Extrusion Moulding (FDM);
- Powder bed fusion (PBF) - includes technologies such as Selective Laser Sintering (SLS), Laser Synthesis (melting) of Metals (SLM) technology;

- Sheet lamination - includes lamination object manufacturing (LOM) and ultrasonic additive manufacturing (UAM) technologies;
- Direct Energy Deposition - encompasses Laser Net Engineering Form (LENS) and Electron Beam Additive Manufacturing (EBAM).

Additive manufacturing (AM) is a genuinely innovative technology that presents new opportunities for companies seeking to significantly enhance their production efficiency compared to traditional methods. It has the potential to become a mainstream technology in the coming years and to play an important role in Industry 4.0 and Industry 5.0.

There are several key advantages, evidenced in Fig. 6, of additive manufacturing over traditional manufacturing (subtractive and formative) in terms of cost, speed of production, quality, innovation/transformation and impact (Mohsen, 2017).

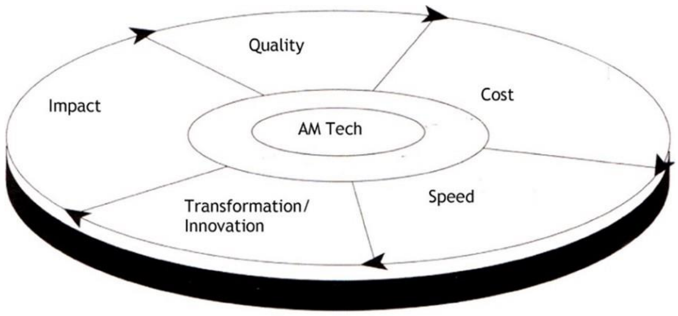

Fig. 5 – Key Advantages of Additive Manufacturing (Mohsen, 2017).

In addition to the advantages outlined above, additive manufacturing also has a limited number of disadvantages, such as:

- Additive manufacturing processes often use liquid polymers or a powder composed of resin or plaster to build up layers of objects. These materials make additive manufacturing unable to produce large objects due to the lack of strength of the material.
- For large series of products or large items, long production times are often required to complete the process of obtaining them.
- Lack of processable materials.
- Lack of repeatability(multiplication).

The evolving requirements of the majority of industries utilising additive manufacturing will determine the trajectory of additive manufacturing and the nature of technological innovations that align with market demands. New technologies are transforming the consumer experience, the way business models function, the distribution of goods, and the way industries operate. The figures illustrate the robust growth of the additive manufacturing market. The factors driving the rapid growth of the industry are the reduction in the cost of accessing technology and an increase in the number of applications (Mohsen, 2017).

The scope and impact of additive manufacturing continues to expand as the technology becomes accepted and proves its functionality, making it a feasible means of production in a variety of industries. The technology offers a multitude of potential applications, which has led to a trend towards these two main categories of use: rapid prototyping and component manufacturing (Mohsen, 2017).

It is evident that technology trends have played a significant role in shaping and predicting the future of additive manufacturing. The advancement of automotive and aerospace technologies has and will continue to influence the development of additive manufacturing in these industries. The evolving requirements of the majority of industries that utilise additive manufacturing will influence the trajectory of additive manufacturing and the nature of technological innovations that align with market demands. New technologies are transforming the consumer experience, the way business models function, the distribution of goods, and the manner in which industries operate (Mohsen, 2017).

3.2. Collaborative robots

The term robotics has recently been defined as the science that studies the intelligent connection between perception and action. Industrial robotics is a discipline that deals with the design, control and applications of robots in industry (Wallén, 2008). The positioning of robotic technology can be reflected by the definition of robot as stated by the Robot Institute of America: "A robot is a reprogrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable movements, programmed to perform a variety of tasks" (Wallén, 2008). The International Organization for Standardization, ISO, has formulated a definition of industrial robots that most organizations today have more or less agreed with:

"The industrial handling robot is a controlled, reprogrammable, multi-functional, multi-degree-of-freedom, manipulative machine that can be either stationary or mobile for use in industrial automation applications" (Wallén, 2008).

In turn ISO has used in its definition the word manipulator which is nothing else than the arm used by the robot and whose definition is found below:

- "Manipulator is a machine, the mechanism of which usually consists of a series of segments which are joined or slide relative to each other for the purpose of gripping and/or moving objects (parts or tools), after several degrees of freedom" (Wallén, 2008).

Industrial robot handlers have been classified according to ISO 8373:2021 and are organized according to their construction structure into 7 categories:

- Cartesian robots
- Cylindrical robots
- Spherical robots
- Roboti tip SCARA(Selector Complains Arm for Robotics Assemble)
- Parallel robots
- Articulated robots
- Pendulum robots

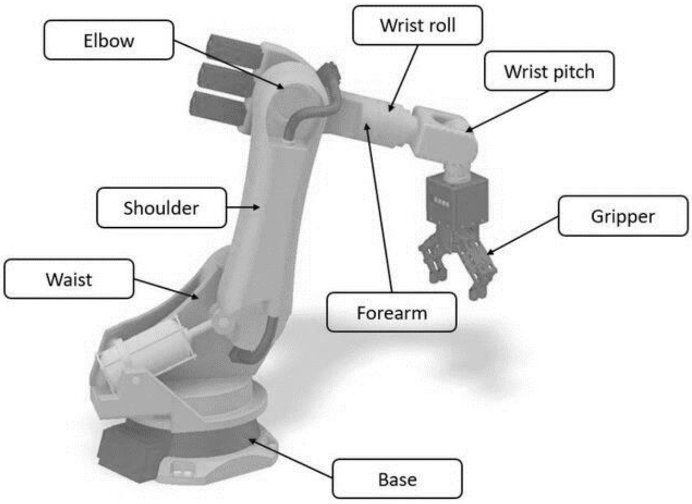

Fig. 6 – Main parts of an industrial robot (Păduraru *et al*., 2023).

The term "industrial robot" is used to describe a robot employed in industrial settings. These robots are utilized in a variety of operations, including the movement, organization, and supply of materials and products (Ben-Ari *et al*., 2018). In order to perform its functions, the industrial robot must have in its structure the component parts resulting from the aforementioned sources (Păduraru *et al*., 2023).

The main functions performed by the industrial robot are (Chitariu., 2022):

- work functions;
- control and programming functions;
- measurement and recognition functions.

An understanding of the production needs and long-term goals is a fundamental aspect in the selection of industrial robots that are most suitable for a given context. Industrial robots possess both advantages and disadvantages, as outlined below. Among the advantages we can mention:

- Increase productivity through the ability of robots to perform continuous, repetitive work tasks with precision and accuracy, improving high production requirements;
- Automating processes by programming robots to perform various tasks, thus reducing the need for human intervention;
- Improved safety by using robots in hazardous environments, eliminating the risk of injury or harm to human workers;
- The precision and accuracy of robots that are designed to perform tasks with the highest precision and accuracy, resulting in consistent quality and reduced errors.
- As disadvantages we can mention:
- High upfront costs for purchasing robots for small and medium-sized enterprises.
- Limited flexibility as robots are programmed to perform specific tasks and do not have the ability to adapt to changing requirements or situations.

As illustrated in Fig. 7, it can be observed that there is an emerging trend in technological evolution, with a focus on connectivity and human-centred collaboration that is driving an increase in the implementation of robots within manufacturing sectors. In light of this, it can be anticipated that new development models will emerge in the near future, with the introduction of robots and the creation of new production units.

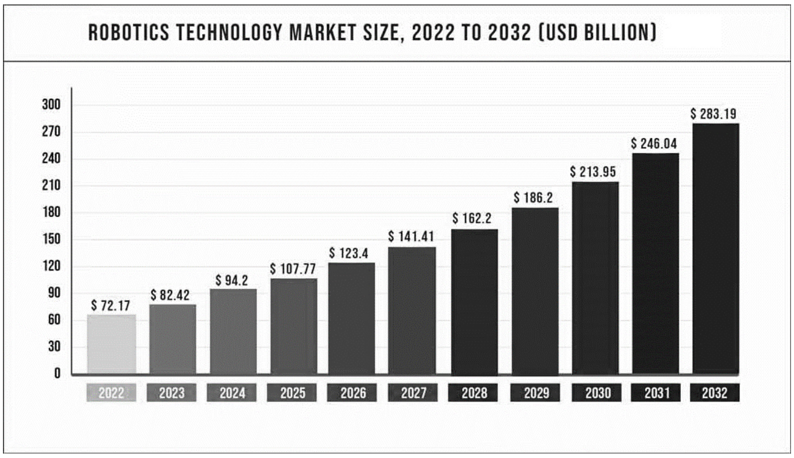

Fig. 7 – Robotics Technology Market Size 2022-2032
(Precedence Research Pvt. Ltd., 2024).

The Industry 5.0 concept, therefore, proposes the intelligent factory as a solution through the three characteristics of human-centredness, sustainability and resilience. This factory would be much easier to adapt, with production lines that are not only easy to use but also adapted to different products or processes.

3.3. Simulation and Augmented Reality

The term "simulation/digital twin" is used to describe the capacity to virtually represent and optimise a product or production process.

The distinction between CAD-CAM and CAE and the digital twin lies in the latter's capacity to record, structure and synchronise all data pertaining to a product, encompassing its conceptualisation, design, manufacture, launch, utilisation, maintenance and disposal, as well as recycling.

A concept model proposed in Industry 4.0 for understanding how the digital twin works is illustrated below in Fig. 8. This comprises a six-step approach that includes the following stages: creation, communication, aggregation, analysis, insight and action (Pires *et al*., 2019).

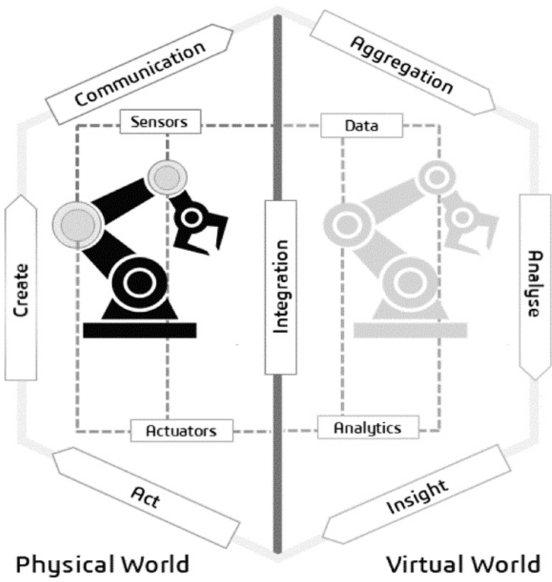

Fig. 8 – Digital Twin - working model (Pires *et al*., 2019).

Augmented Reality (AR), is an innovative technology that has experienced a marked development in recent years, reaching such an important level that a series of definitions, unanimously accepted, have been proposed and which refer to:

- a technology that can combine the real and virtual, interact in real time and record in 3D, creating an immersive and interactive experience through graphic overlays, video streams or holograms in the physical world (Yin *et al*., 2022).
- a fusion of the real world and virtual information so that this concept can be defined as "any scenario in which the authentic environment is enhanced by the use of virtual (computer-generated) objects" (Çöl *et al*., 2023).

In the context of augmented reality, overlay augmented reality employs object recognition techniques to facilitate the generation of a virtual experience.

The augmented image either partially or completely replaces the original image. The two fundamental types of augmented reality overlay are achieved through two distinct techniques, namely "marker-based" and "markerless". The latter encompasses four distinct subcategories, as illustrated in Fig. 9.

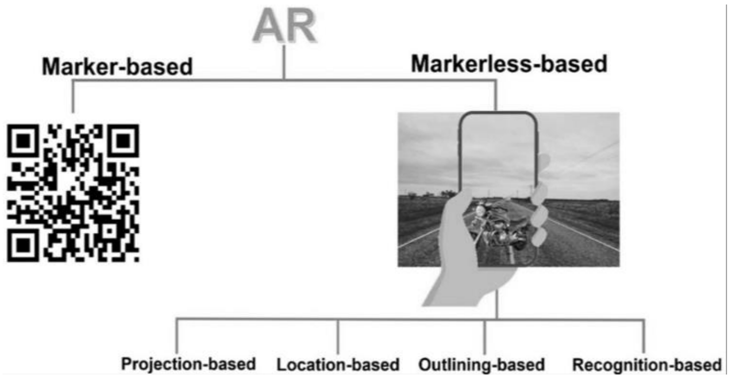

Fig. 9 – Basic types of augmented reality overlay (Malta *et al*., 2023).

AR alters our perception of relationships with industry, manufacturing, education and so on, improving creativity and human development, training the mind to use applications. Some of the major benefits to society are listed below (Nagpal *et al*., 2022):

- The time required for interaction between real and virtual is very low;
- Improves perception and interaction with the physical world;
- It's easy to use, so it can be used by anyone;
- Reduced costs by using the AR technique to test critical situations and once tested, situations can be implemented in real time.
- A useful technique for the military because they can use battlefield simulation before the actual war;

- Users can interact with life-size 3D models, both with (and without) tracking devices;
- the ability to observe the user's location, e.g. on the map, on the 3D AR GPS compass;
- Users can use apps to save the location from GPS and place it on a real scene with size adjustment (Iatsyshyn *et al*., 2019);
- Applications of AR technologies increase motivation to learn, increase the level of assimilation of information due to the variety and interactivity of its visual presentation (Nagpal *et al*., 2022);

The technology used in Augmented Reality not only presents advantages but also creates certain problems in a number of areas, such as:

- has an impact on the user's health (eye disease, mental illness and body posture-ergonomics problems at work);
- can misinterpret the speed of oncoming traffic in traffic and reduce reaction times;
- a major limitation during testing of some situations due to low performance of AR devices;
- Lack of privacy is a concern in AR-based applications as capturing images and random scenes of private property as well as recording conversations is illegal in some jurisdictions under strict privacy laws;
- developing and maintaining AR-based projects is very costly as it requires the collection, generation and analysis of large sets of data, thus causing Security issues (Nagpal *et al*., 2022; Iatsyshyn *et al*., 2019).

It is anticipated that the augmented reality (AR) market will experience growth over the forecast period, as may be observed in Fig. 10.

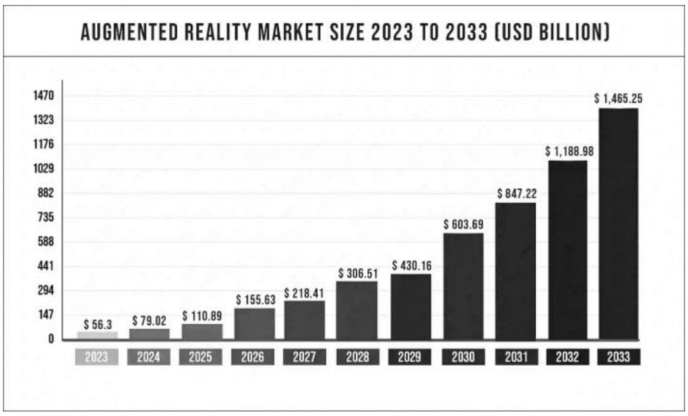

Fig. 10 – AR Market Size 2023-2033 (Precedence Research Pvt. Ltd., 2024).

This is due to the fact that companies are seeking to leverage this technology in novel ways, with a particular emphasis on providing a distinctive and engaging experience for end-users.

A significant factor driving this growth is the increasing prevalence and adoption of mobile augmented reality technology, facilitated by the rising use of handheld devices such as smartphones and smart glasses.

This development is anticipated to play a pivotal role in expanding the market, enabling a more immersive and interactive experience that can be enjoyed on the go.

3.4. Artificial Intelligence

Artificial Intelligence (AI) can be seen as a central element of the digital transformation of society and can be defined as either

- a machine learning system, or the replication by machines of human-specific cognitive abilities (AI - Artificial Intelligence),
- being the systematic component that focuses on the development, validation, implementation and maintenance of AI solutions (in their various forms) for industrial applications with sustainable performance (Peres *et al.*, 2020)

In recent years, considerable research efforts have been made in the field of AI in order to combine the concepts of ML "Machine Learning", NPL "Natural Language Processing", CV "Computer Vision" and Robotics and integrate them into the production value chains of Industry 4.0. (Peres *et al.*, 2020). These concepts also represent the components of AI as presented in Fig. 11 (Goutham, 2020).

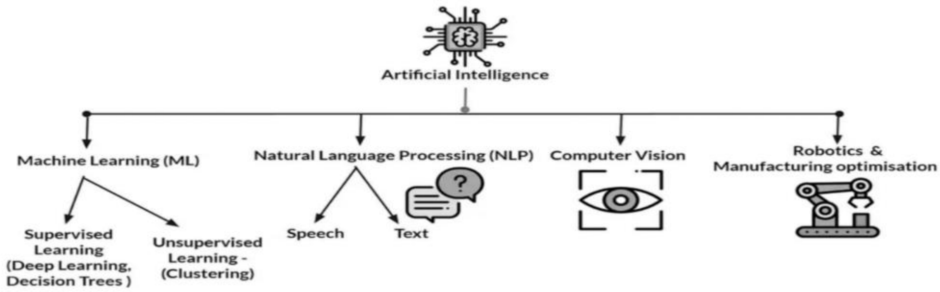

Fig. 11 – AI components (Goutham, 2020).

While artificial intelligence has numerous advantages, it also presents certain disadvantages. The benefits of artificial intelligence include efficiency through automation of tasks, data analysis for informed decision-making, assistance in medical diagnosis and the advancement of autonomous vehicles (Duggal, 2024). The disadvantages of artificial intelligence include the potential for it to replace humans in the workplace, ethical concerns about bias and privacy, security risks from hacking, and a lack of creativity and human empathy (Duggal, 2024).

In terms of manufacturing, AI can assist European manufacturers in becoming more efficient and in bringing factories back to Europe. This can be achieved by using robots in manufacturing, optimising sales and anticipating maintenance or disruptions early in smart factories (Parliament, 2020).

Although some AI technologies have been in existence for over half a century, the increase in computing power, the availability of vast quantities of data and the development of new algorithms have led to significant advances in AI in recent years. Future applications are expected to bring about profound changes, but AI is already present in our daily lives (Parliament, 2020).

The growing prevalence of life-saving medical devices and the advent of autonomous vehicles are driving the expansion of the AI market on a global scale, conform Fig. 12.

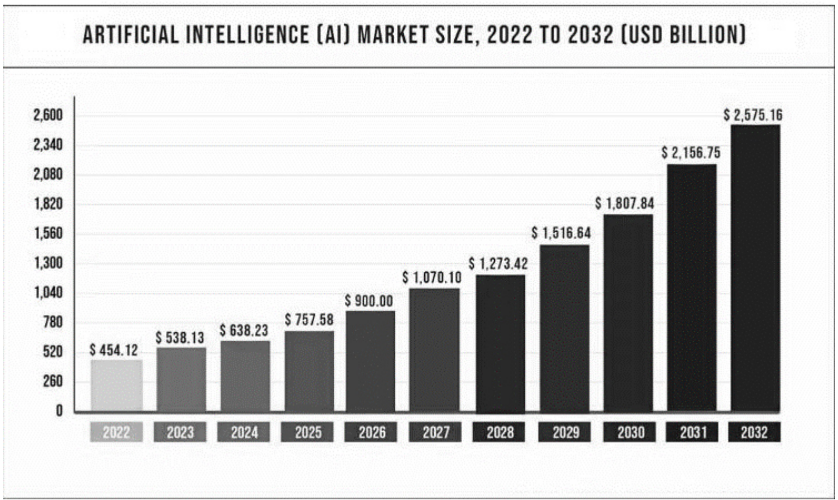

Fig. 12 – AI Market Size 2022-2032 (Precedence Research Pvt. Ltd, 2024).

In parallel, the higher demand for automated and technologically advanced hardware and software products across various end-use verticals, in combination with the favourable government policies that encourage the industries to adopt artificial intelligence, has significantly contributed towards the growth of the artificial intelligence market.

It was realised that there was a need for hardware-based artificial intelligence products due to the fact that end-use applications demanded lower power and higher performance.

4. Conclusions

The objective of this paper is to draw attention to a topic of general interest, namely Industry 5.0, within an intensely researched field such as industrial engineering.

It is evident that Industry 5.0 builds upon the ideology of Industry 4.0, with a focus on the human being at the centre of industrial production processes. In order for a transition to occur from a high-performance industrial strategy (Industry 4.0) to one that is centred on human well-being (Industry 5.0), there must be an equilibrium established among performance, technologies (digitisation), and human well-being.

To illustrate the 5th industrial revolution, it is necessary to consider the following example. In Industry 5.0, there is a focus on the combination of highly-skilled human resources with robots, in order to produce a diverse range of consumer products, from smart devices to cars.

The transition from mass production to mass personalisation has the potential to raise concerns about productivity and sustainability. Historically, there have been challenges associated with customer preferences, affordability and delivery time.

The concept of sustainability considers three interlinked pillars: the economy, the environment, and society, with a focus on finding solutions to the challenges posed by the current model of production and consumption. Therefore, there is a case to be made that the transition to a more sustainable model of manufacturing is critical for the development of society, with particular focus on the development of renewable energy sources. Sustainability is dependent on the innovation of products and services, and therefore the ability of manufacturers to adapt to the changing demands of consumers and society.

In essence, a resilient industry is characterised by a high degree of robustness. It is firmly embedded in the economic sphere, able to withstand disruptions and to support critical infrastructure in times of crisis.

Consequently, the key to a resilient organisation is normality, which entails continuous change and adaptation. Stability, however, should be regarded as an economic mechanism that functions over a limited period of time.

One example of this can be found in the pandemic period, which served to highlight industrial vulnerabilities and the importance of greater agility and resilience in supply chains and other components of production. Consequently, the attainment of a high degree of resilience is regarded as a fundamental competency of Industry 5.0.

It is our contention that the subject matter under discussion will prove to be of value in view of the digital transformation that is impacting on the way manufacturing processes are carried out. We are currently engaged in an era of digitisation in this field and beyond. The information presented in this paper adheres to the characteristics of a work that presents the current state of development of the concept of Industry 5.0. It does so by presenting the news, challenges, opportunities, restrictions, threats and fears related to the implementation of this concept.

It is therefore of great importance for those working in industrial engineering to familiarise themselves with these pillars, as they are expected to have a widespread impact across industries and throughout society.

In light of the preceding discussion, it becomes evident that the advent, evolution, and continuous improvement of the pillars of the Industry 5.0 concept, particularly the four pillars of Additive Manufacturing, Robotics, Augmented Reality, and Artificial Intelligence, have initiated a profound transformation in the industrial landscape, on a global scale, comparable to a true industrial revolution. This transformation is driven by efforts to actualize the promised benefits of the digital world in tangible industrial settings.

The value added by this work is to generate new insights into future research directions. This is achieved by incorporating novel factors in studies, introducing new variables, or redefining existing ones. The scope is not constrained to any particular aspect.

For industry to become the provider of true prosperity,the definition of its true purpose must include social, environmental and societal considerations. This includes responsible innovation, not only or primarily aimed at increasing cost-efficiency or maximising profit, but also at increasing prosperity for all involved: investors, workers, consumers, society, and the environment.

REFERENCES

Ashima R. *et al.*, *Automation and manufacturing of smart materials in additive manufacturing technologies using Internet of Things towards the adoption of industry 4.*0, J. Materials Today: Proceedings, Vol. 45(6), 2021, Page 5081-5088, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2021.01.583.

Ben-Ari M. et al., *Elements of robotics*, Springer Cham, 2018, ISBN 978-3-319-62533-1, https://doi.org/10.1007/978-3-319-62533-1.

Breque M. et al., *Industry 5.0 Towards a sustainable, human-centric and resilient European industry*, In Industry 5.0 Towards a sustainable, human-centric and resilient European industry, 2021, Luxembourg: Publications Office of the European Union.

Chitariu D., Curs Robotică și sisteme robotizate (2022).

Çöl B.İ. et al., *Virtual reality and augmented reality technologies in gastronomy: A review*, Wiley Online Library, March 2023, https://doi.org/10.1002/efd2.84.

Dikhanbayeva D. et al., *Assessment of Industry 4.0 Maturity Models by Design Principles*, J. Sustainability, Vol. 12(23), 2020, https://doi.org/10.3390/su12239927.

Duggal N., https://www.simplilearn.com, (Simplilearn Americas, Inc.) Retrieved, 2024, from https://www.simplilearn.com/advantages-and-disadvantages-of-artificial-intelligence-article.

Goutham R., (2020), Retrieved 12 8, 2022, from MEDIUM: https://medium.com/.

Iatsyshyn A.V. et al., *Application of augmented reality technologies for preparation of specialists of new technological era*, Conference: 2nd International Workshop on Augmented Reality in Education, AREdu 2019, Kryvyi Rih, Ukraine.

Jandyal A. et al., *`3D printing – A review of processes, materials and applications in industry 4.0*, ScienceDirect, J. Sustainable Operations and Computers, Vol. 3, 2021, Page 33-42, https://doi.org/10.1016/j.susoc.2021.09.004.

Kumar A. et al., *Industry 4.0: Evolution, Opportunities and Challenges*, International Journal of Research in Business Studies, ISSN: 2455-2992, Vol. 5 (1), June 2020.

Leng J. et al., *Industry 5.0: Prospect and retrospect*, Journal of Manufacturing Systems, Vol. 65, 2022, Page 279-295, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2022.09.017.

Malta A. et al., *Augmented Reality in Maintenance–History and Perspectives*, J. Imaging, Vol. 9(7), 2023, 142, https://doi.org/10.3390/jimaging9070142.

Mohsen A., *The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing*, Journal ScienceDirect, J. Business Horizons Vol. 60, Issue 5, 2017, Page 677-688, https://doi.org/10.1016/j.bushor.2017.05.011.

Mourtzis D. et al., *Operator 5.0: A Survey on Enabling Technologies and a Framework for Digital Manufacturing Based on Extended Reality*, Journal of Machine Engineering, 2022, https://doi.org/10.36897/jme/147160.

Nagpal S.D. et al., *Augmented Reality: A Comprehensive Review*, Arch Computat Methods Eng, Vol. 30, 2023, 1057-1080, https://doi.org/10.1007/s11831-022-09831-7.

Păduraru E. et al., *Research on Additive Technique Parameter Optimization for Robotic Gripper Construction*, MDPI Journals, 2023, https://doi.org/10.3390/machines11060621.

Parliament European, Spokesperson: Jaume Duch Guillot, 2020, Retrieved from, https://www.europarl.europa.eu/topics/en/article/20200827STO85804/what-is-artificial-intelligence-and-how-is-it-used.

Pérez-Lara M. et al., *Vertical and horizontal integration systems in Industry 4.0*, Springer Science+Business Media, 2018, https://doi.org/10.1007/s11276-018-1873-2.

Peres R.S. et al., *Industrial Artificial Intelligence in Industry 4.0 - Systematic Review*, Challenges and Outlook, IEEE Access, Vol. 8, 2020, Page 220121-220139, https://doi.org/10.1109/ACCESS.2020.3042874.

Pires F. et al., *Digital Twin in Industry 4.0: Technologies, Applications and Challenges*, IEEE 17th International Conference on Industrial Informatics (INDIN), Helsinki, Finland, 2019, Page 721-726, https://doi.org/10.1109/INDIN41052.2019.8972134.

Prakash K.S. et al., *Additive Manufacturing Techniques in Manufacturing - An Overview,* Materials Today: Proceedings, Vol. 5(2), 2018, Part 1, Page 3873-3882, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2017.11.642.

Precedence Research Pvt. Ltd., Precedence Research, 2024 April, Retrieved from https://www.precedenceresearch.com/ https://www.precedenceresearch.com/artificial-intelligence-market.

Precedence Research Pvt. Ltd., Precedence Research, 2024 April, Retrieved from https://www.precedenceresearch.com/ https://www.precedenceresearch.com/augmented-reality-market.

Precedence Research Pvt. Ltd. Precedence Research, 2024 April, Retrieved from https://www.precedenceresearch.com/ https://www.precedenceresearch.com/robotics-technology-market.

Rajab S. et al., *Using Industry 4.0 Capabilities for Identifying and Eliminating Lean*, Procedia CIRP, Vol. 107, 2022, Page 21-27, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2022.04.004.

Tavares M.C. et al., *The Challenges and Opportunities of Era 5.0 for a More Humanistic and Sustainable Society–A Literature Review*, J. Societies, Vol. 12(6), 2022, 149, https://doi.org/10.3390/soc12060149.

Vaidya S. et al., *Industry 4.0 – A Glimpse*, Procedia Manufacturing, Vol. 20, 2018, Page 233-238, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2018.02.034.

Wallén J., *The history of the industrial robot. Technical report from Automatic Control*, Report no.: LiTH-ISY-R-2853, Linköpings Universitet, Department of Electrical Engineering, 2008, ISSN 1400-3902, Linköpings.

Xu X. et al., *Industry 4.0 and Industry 5.0–Inception, conception and perception*, Journal of Manufacturing Systems, Vol. 61, 2021, Page 530-535, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2021.10.006 .

Yin Y. et al., *A state-of-the-art survey on Augmented Reality-assisted Digital Twin for futuristic human-centric industry transformation*, Robotics and Computer-Integrated Manufacturing, Vol. 81, 2023, 102515, ISSN 0736-5845, https://doi.org/10.1016/j.rcim.2022.102515.

PILONII INDUSTRIEI 5.0 UTILIZAȚI ÎN INGINERIA INDUSTRIALĂ

(Rezumat)

Domeniul Inginerie Industriale a avut dintotdeauna ca obiectiv principal optimizarea proceselor industriale, a sistemelor complexe prin dezvoltarea, îmbunătățirea și implementarea sistemelor integrate care au la baza resurse umane, resurse financiare, informații, echipamente tehnologice, materii prime și materiale. Transformarea digitală a mediului de afaceri începută încă de la sfârșitul secolului XX a captat atenția mai multor organizații industriale și guvernamentale care s-au concentrat pe cunoșterea și cercetarea conceptului Industria 4.0(I4.0) în toate fazele începând cu inițiere, dezvoltarea acestui concept și maturizarea, urmărind ca valorificarea acestuia să fie doar o trecere (transformare) către următoarea revoluție industrială generic denumită Industria 5.0(I5.0). Acest nou concept I5.0 a fost adus în discuție de cercetători și specialiști cu ceva timp în urmă și sugerează acea fază a industrializării despre care se dorește a fi o corecție de mult așteptată a conceptului I4.0. făcând ca producția să respecte limitele existente în acest moment, însă poziționând bunăstarea lucrătorului

industrial în centrul procesului de producție astfel încât să putem redescrie conceptul Industria 5.0 în principal prin dimensiunea centrată pe om/valoare.

Această lucrare își propune reliefarea potențialului de dezvoltarea și impactul pilonilor conceptului I5.0: fabricația aditivă, roboți industriali, realitate augumentata, inteligență artificială, și implicațiile acestora în sectoarele industriale care afectează procesul de fabricație. Se are în vedere perspectiva prin prisma celor trei principii propuse de I5.0: centrarea pe om, durabilitatea și reziliența, care conturează aceste noi tehnologii de fabricație folosite în vederea îmbunătățirii proceselor de producție din majoritatea domeniilor, inclusiv din domeniul ingineriei industriale. Pilonii conceptului I5.0 prezentați în această lucrare vor descrie amplificarea acestei transformări digitale și colaborarea mai semnificativă și mai eficientă între oameni și mașinile și sistemele din ecosistemul lor digital astfel încât parteneriatul dintre oameni și mașinile inteligente să îmbine acuratețea și viteză automatizării industriale cu creativitatea, inovația și abilitățile de gândire critică ale oamenilor. Aşadar, indiferent de modalitatea de definire a conceptul I5.0, este important de specificat că acești piloni stau la baza unei noi revoluție industriale și definesc un nou nivel de organizare și control asupra întregului lanț valoric al ciclului de viață al produselor.