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Original Contribution

EVOLUTION OF INDUSTRIAL SYSTEMS: FROM THE HUMANIZATION OF INDUSTRY 5.0 TO THE BIO-DIGITAL SYMBIOTIC INDUSTRY 6.0

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Abstract: *At the beginning of the 21st century, the world witnessed the Fourth Industrial Revolution (Industry 4.0), which laid the foundations for digitalization, cloud computing, and the Internet of Things (IoT). Despite undeniable technological successes, Industry 4.0 faced criticism for its "technocentricity" a model in which machine efficiency often took precedence over human well-being and ecological balance.*

Key words: *Industry, Internet of Things (IoT), Technocentricity.*

1. Introduction

This paper explores the logical sequence of the next two phases. Industry 5.0 appears as a “corrective mechanism” that brings the human factor and sustainability back to the heart of production. On the other hand, Industry 6.0 represents a futuristic leap that goes beyond simple automation to full integration between biological systems, quantum computing and hyper-connectivity.

1. Industry 5.0. The human at the center of intelligent manufacturing

1.1. Essence and social mission

Industry 5.0 is not just a technological upgrade, but a paradigm shift [4,5]. It focuses on three main pillars: human-centricity, sustainability and resilience [8]. The goal here is not to completely replace human labor, but to create an environment in which "smart" machines and people collaborate to achieve higher added value through creativity and personalization [7,9].

1.2. Technological tools

A key element in this phase is collaborative robotics (Cobots). Unlike their predecessors, these robots are equipped with advanced safety sensors, allowing them to work without physical barriers to humans [8,9].



Fig. 1. Collaboration model in Industry 5.0 [author, AI-generated]

In this model, AI processes large data sets and performs the heavy physical work, while humans focus on strategic decision-making, design, and ethical oversight [12].

1.3. Mass Personalization vs. Mass Production

One of the most significant changes is the transition from "MassProduction" to "MassPersonalization". Thanks to flexible production cells and 3D printing, industry can now produce unique products for each user (e.g. personalized shoes or medical prostheses) at the cost of mass production.

2. Industry 6.0. - the era of cognitive singularity

While Industry 5.0 is still unfolding, the scientific community is starting to outline the contours of Industry 6.0. This new phase is defined by the concept of bio-digital symbiosis [11,13].

2.1. Quantum computing and 6G connectivity

Industry 6.0 will rely on 6G networks, which will provide speeds of up to 1 Tbps and latency below 1μs. This will make it possible to manage global production networks in real time through holographic presence. Quantum computers will optimize complex logistics chains in fractions of a second - a task that today takes days..

2.2. Brain-Computer Interface (BCI) and Bio-integration

The most revolutionary aspect of 6.0 is the integration of the human mind with the machine. Through neural interfaces, workers (now called “cognitive operators”) will be able to control nano-robots or complex systems directly with their thoughts. This removes physical barriers to productivity [12,13].



Fig. 2. Digital architecture (diagram) of a solar panel manufacturing process [author, AI-generated]

Connecting all machines (IoT integration) Installing sensors for temperature, vibration, speed, defects. Each machine sends real-time data to central software. Cloud platform for data collection and analysis. Result: Full visibility over production in real time. 2 Using AI for quality control Machine vision cameras to detect microcracks or defects. Algorithms to automatically reject defective panels. Self-learning models to improve accuracy.

Result: Less waste and higher quality. 3 Digital Twin Create a virtual model of the production line. Simulate changes before they are actually implemented. Optimize speed, workload, and costs. Result: Reduced risk and faster optimization.4 Predictive maintenance AI analyzes vibrations and wear. Predicts when a machine will fail. Automatically schedules service. Result: Fewer unplanned downtime. 5 ERP + MES integration Connecting production with: warehouse deliveries sales Automatic planning according to orders. Result: More flexible and efficient production. 6 Autonomous logistics AGV robots (autonomous carts) for transporting materials. RFID tracking of each unit of production. Result: Full traceability.[3,9]

"A high-tech, futuristic industrial environment representing Industry 6.0. Showcasing the fusion of biological elements such as glowing neural networks and digital interfaces. A human operator wearing a discrete headset with a neural interface interacting with holographic quantum data visualizations. In the background - microscopic nano-manufacturing machines and 6G connecting beams. Elegant, clean, blue-gold color palette, cinematic lighting, academic and visionary style" [11,12,13].

3. Comparative analysis: Evolutionary leap and structural differences

The logical connection between the two paradigms can be traced through the transition from "collaboration" to "fusion". The following table synthesizes the main differences that define each era [4].

Table 1. Comparative characteristics of Industry 5.0 and Industry 6.0

Criterion	**Industry 5.0 (Present/Near Future)**	**Industry 6.0 (Futuristic horizon)**
Main focus	Harmony between man and machine	Bio-digital integration and symbiosis
Connectivity	5G, IoT, Cloud Computing	6G, Satellite Quantum Internet
Intellect	Artificial Intelligence (AI) as a Tool	Quantum and cognitive intelligence
Materials	Recyclable and "smart" materials	Molecular and nano-manufacturing
Interaction	Physical (via cobots and AR/VR)	Neural (via BCI and holograms)
Ecology	Circular economy (Net Zero)	Regenerative economy (Positive Impact)
Risks	Substitution of low-skilled labor	Cyber-biological attacks, ethical dilemmas

4. Challenges and ethical considerations

The transition to these new stages is not without its challenges.

1. **The digital divide:** There is a risk that countries and companies that fail to implement 5.0 and 6.0 will remain in "technological isolation".
2. **Neural Security:** In Industry 6.0, the concept of cybersecurity is expanded to "thought protection." Hacking a BCI interface would mean direct access to an individual's cognitive processes.
3. **Environmental imperative:** While 5.0 aims for zero footprint, 6.0 must go further by using nanotechnology to actively restore the environment (cleaning up oceans and atmosphere in the manufacturing process) [5,7].

5. Industry 6.0: Human-Machine Symbiosis

Industry 6.0 takes the concept of smart factories to an even higher level. Imagine a manufacturing environment where machines seamlessly collaborate with humans. Advanced technologies such as artificial intelligence (AI), neural interfaces, and robotics will play a bigger role. AI will handle complex decisions, while robots with human dexterity will work together with humans. This frees up human workers for creative tasks and problem-solving, thus maximizing their potential [8,12].

Industry 6.0 of the future is based on sustainability, homogeneous assets, security, sustainability, anti-fragility, harmony with nature, sharing technology (digital twins) and eco-economy [3].

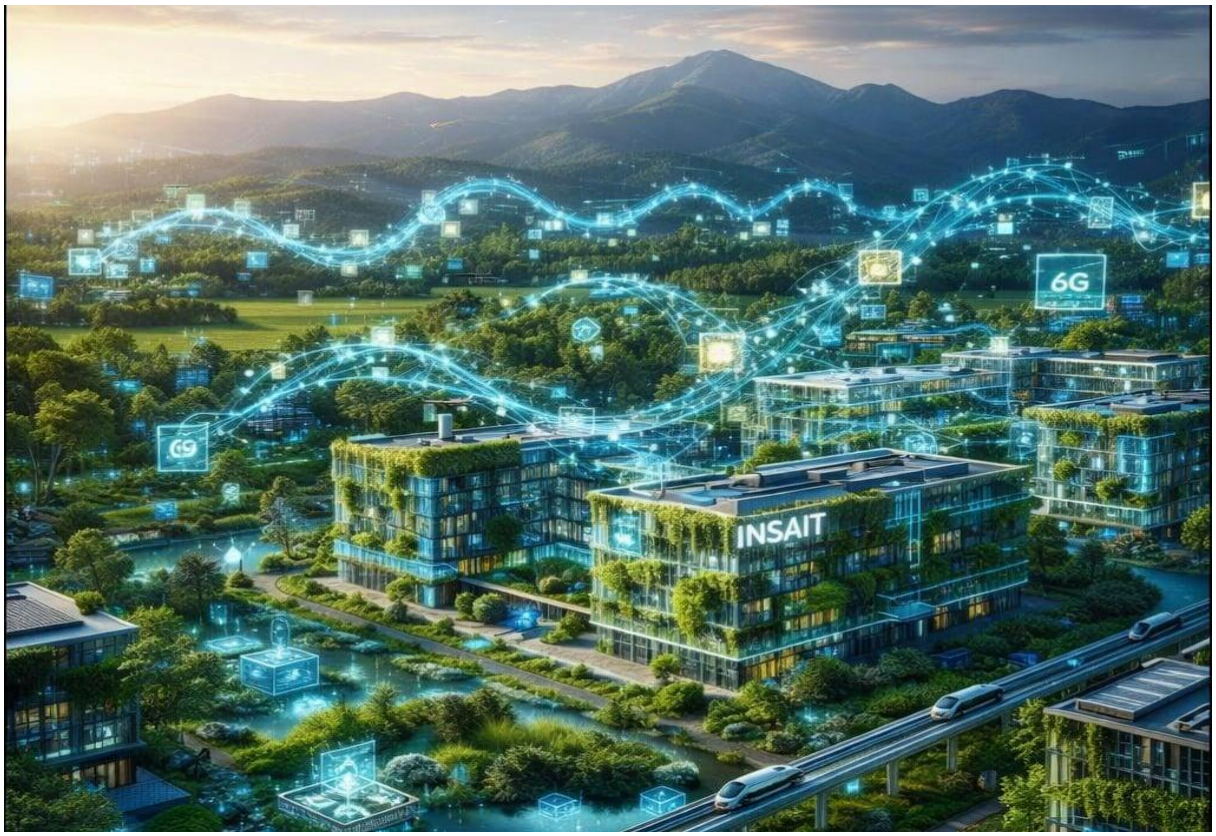


Fig. 3. Industry 6.0. [author, AI-generated]

The transition from Industry 1.0 to Industry 6.0 involves several stages, including the First Industrial Revolution, which introduced manufacturing systems; the Second Industrial Revolution, characterized by mass production and scientific management; the Third Industrial Revolution, marked by automation of computer-controlled machines and robotics; and Industry 4.0, which relies heavily on computing power and technologies for long-term sustainability [3,4,11].

5.1. The Supply Chain Revolution

The supply chain in Industry 6.0 is becoming a dynamic, hyperconnected network. Here's how:

Real-time visibility: Imagine a world where any product can be tracked all its way, from raw materials to your door. This transparency allows for real-time adjustments based on fluctuations in demand or interruptions.

Dynamic Planning: AI-powered systems will analyze vast amounts of data to predict demand and optimize production and logistics. This can mean shorter production cycles with greater customization, eliminating the need for large inventories.

Flexible Manufacturing: Industry 6.0 encourages the shift to localized manufacturing using technologies such as **3D printing**. This reduces reliance on long, complex supply chains and allows for faster response times to customer needs [2].

An example of Industry 6.0 from the footwear industry

Let us see how Industry 6.0 can transform the footwear industry. Traditionally, shoe manufacturers produce large batches based on projected demand. With Industry 6.0, the customer can design their shoes online, with artificial intelligence taking comfort and fit into account. The design will then be sent to a nearby 3D printing that uses sustainable, recycled

materials. This reduces waste and emissions from transportation and creates a hyper-customized product [10].

Industry 6.0 also addresses the challenges associated with providing virtualized antifragile manufacturing and services, focusing on the customer-centric ethos, superconnected industries with dynamic supply chains, automated agility, and internal networks to create value for effective interactions within or outside the organization, between different countries and its policymakers [11,13].

5.2. Industry 6.0. Work in development

Although Industry 6.0 is still in the conceptual stage, several technologies are already paving the way. The way forward includes overcoming challenges such as the ethical considerations of artificial intelligence and human-machine collaboration. However, the potential benefits for efficiency, sustainability, and customization are undeniable. Industry 6.0 promises a future in which factories and supply chains work in harmony with human ingenuity, shaping a more adaptable and human-centric manufacturing landscape. The main focus of the sixth industrial revolution will be on medical technologies with multidimensionally printed controlled-release medicines and fully automated medical diagnostics, removing any additional burden from practitioners and leaving them to focus on critical cases [10,13].

6. Regional context: Bulgaria in the transition to Industry 5.0 and 6.0.

6.1. From "Low-cost destination" to "High-tech hub"

For Bulgaria, the transition to Industry 5.0 represents a historic chance to overcome the "middle income trap". While previous industrial eras relied on cheap labor, Industry 5.0 requires highly skilled human capital, an area where the country has a competitive advantage thanks to its strong ICT sector [1,6].

6.2. Industry 5.0 and the Bulgarian Small and Medium Enterprises (SMEs)

In Bulgaria, the focus of Industry 5.0 is on **the digitalization of traditional industries** (furniture, textiles, food industry). The integration of cobots in Bulgarian factories allows small teams to increase their productivity without the need for large-scale personnel replacement, which is critical given the demographic crisis and staff shortages.

1. *Example: The implementation of AI energy efficiency systems in factories in the Thracian Economic Zone already demonstrates the "Sustainability" pillar of the 5.0 paradigm [6,8].*

6.3. Bulgaria and the horizons of Industry 6.0

Although 6.0 seems like a distant future, Bulgaria is already laying the foundations through:

1. **Artificial Intelligence and Deep Tech:** The creation of institutes such as **INSAIT** positions the country on the world map in the development of fundamental AI - the "brain" of the future Industry 6.0.
2. **Quantum Communications:** Bulgaria is part of the EU's Quantum Communication Infrastructure Initiative (EuroQCI), which is a key element of security in the 6.0 era [6,14].

SWOT analysis of Bulgaria for the Industrial Transformation

Strengths	Weaknesses
Strong software ecosystem and IT talent.	Obsolete material base in heavy industry.
Strategic geographical location.	Slow pace of innovation in small settlements.
Opportunities	**Threats**
Funding under the Recovery and Resilience Plan.	"Brain drain" to Western Europe and the United States.
Leadership in regional supercomputing centers.	Cyber threats to critical infrastructure.

6.4. Visualization of the future

To illustrate what the Bulgarian industrial landscape could look like in 2035, we will generate an image combining traditional Bulgarian nature/architecture with elements of high technology from the 6th generation.

Recommendations for the Bulgarian context

In order for Bulgaria not to remain only a consumer of Industry 5.0 and 6.0 technologies, it is necessary:

1. **Incentivizing research and development (R&D):** Tax breaks for companies investing in quantum computing and biotechnology.
2. **Education Reform:** Integrating STEM Learning with a Focus on Ethics and Cognitive Science.
3. **Cyber Resilience:** A National Strategy to Protect Future Bio-Digital Interfaces [6,14].

Conclusion

Industry 5.0 and Industry 6.0 represent the two ends of the same spectrum - humanity's desire to subordinate technology to its needs, not to submit to it.

1. **Industry 5.0** is the "humanistic renaissance" that teaches us how to live sustainably with robots.
2. **Industry 6.0** is the "technological evolution" that will make manufacturing an organic part of human existence.

For this transformation to be successful, not only technological developments are needed, but also a new educational framework to prepare the next generation of professionals to work in a world where the boundaries between biology and code no longer exist.

The transformation from Industry 5.0 to 6.0 is not just a series of technical specifications, but an evolution of human consciousness and its ability to manage the tools it creates. Bulgaria, with its combination of rich history and modern technological capacity, has the potential to be not only a participant but also a leader in this new "bio-digital" era.

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