DEVELOPMENT DIRECTIONS OF INFORMATION SYSTEMS IN THE CONTEXT OF INDUSTRY 5.0

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Abstract: Industry 5.0 marks a shift to a human-centric, sustainable industrial era, focusing on human-machine collaboration and environmental responsibility. It builds on Industry 4.0's digital foundation, integrating cognitive computing and robotics for personalized, resilient production. The concept emphasizes sustainability, circular economy principles, and ethical design. Research highlights human-robot cooperation and resilient manufacturing to address modern challenges like supply chain disruptions. In Serbia, AI development plays a crucial role in this transition. The country's AI strategy supports education, innovation, and infrastructure to promote sustainable economic growth, aligning with Industry 5.0 principles and advancing both technologically and ethically.

Key words: Industry 5.0, sustainability, human-machine collaboration, circular economy, AI strategy, ethical design.

1. INTRODUCTION

The concept of Industry 5.0 marks a significant shift in industrial development, focusing on human-centric and sustainable production practices. Building on the advancements of Industry 4.0, Industry 5.0 emphasizes the collaboration between humans and machines, the integration of cognitive computing, and a commitment to environmental responsibility. As industrial processes evolve, the need for resilient manufacturing and sustainable practices has become evident, particularly in the face of global challenges such as supply chain disruptions. In this context, the role of information systems becomes critical in enabling the efficient integration of advanced technologies to support sustainable and personalized production. This paper explores the development directions of information systems in the context of Industry 5.0, highlighting the need for innovative software solutions that foster collaboration, sustainability, and resilience.

2. RELATED WORKS

The concept of Industry 5.0 has garnered significant attention in recent years, driven by its focus on human-centric industrial practices and its emphasis on sustainability and resilience. Early research in this domain highlights the evolution from Industry 4.0 to Industry 5.0, where the latter integrates human intelligence with advanced machine capabilities. Leng et al. (2022) provide a comprehensive review of Industry 5.0, summarizing its connotations, architecture, and enabling technologies. Their work identifies key trends, including human-robot collaboration, cognitive systems, and resilient manufacturing, emphasizing the alignment of industrial processes with societal needs [1]. Barata and Kayser (2023) further analyze the transition, categorizing research into three distinct phases since 2018. They stress the significance of circular manufacturing and sustainable practices in shaping Industry 5.0, illustrating its divergence from the technology-centric focus of Industry 4.0. Their bibliometric analysis sheds light on societal priorities that industries must consider in digital transformation initiatives [2]. Similarly, Alojaiman (2023) discusses the potential of Industry 5.0 in addressing modern challenges such as supply chain disruptions and healthcare demands, highlighting the collaboration between humans and robots to create adaptive and robust systems [3]. Additionally, Todoshchuk et al. (2023) explore the implications of Industry 5.0 on economic security, particularly in personnel management systems [4]. Their research offers novel insights into modeling information systems to enhance economic stability during this transformative phase. The integration of digital interaction between humans and machines, as proposed, ensures a seamless transition to Industry 5.0 while safeguarding socio-economic interests.

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3. HISTORICAL DEVELOPMENT OF INDUSTRIAL REVOLUTIONS AND THE CONCEPT OF INDUSTRY 5.0

Industrial revolutions represent historical milestones that have transformed the way human civilization operates, introducing new technologies, production systems, and work organization. The First Industrial Revolution, which began in late 18th-century Britain, was marked by the advent of mechanical production enabled by steam engines. This period witnessed a significant transition from manual labor to machine production, radically altering the economic and social structures of the time. Innovations such as steam locomotives and textile machines spurred trade and urbanization but also introduced new social challenges, including worker exploitation and the absence of labor regulations.The Second Industrial Revolution, emerging in the late 19th century, brought the electrification of production, mass manufacturing, and the development of transportation and communication networks. The integration of electricity into industry enabled faster and more efficient production, while innovations like the assembly line—popularized by Henry Ford—ushered in the era of mass production. This revolution also led to significant advancements in science and technology, such as the telephone, telegraph, and automobile, improving global connectivity for both individuals and businesses. The Third Industrial Revolution, also known as the Digital Revolution, began in the mid-20th century, introducing electronic devices, computers, and the internet, which marked the onset of digitalization. This revolution fundamentally changed how information is processed, stored, and shared, laying the foundation for a knowledge-based global economy. Advances in information and communication technologies facilitated the automation of many industrial processes, while the rise of the internet enabled new business models like e-commerce and global organizational networks. The Fourth Industrial Revolution, or Industry 4.0, started in the early 21st century and is characterized by artificial intelligence, the Internet of Things (IoT), robotics, big data, and other advanced technologies. This era emphasizes full automation of production processes through intelligent systems capable of real-time data analysis and decision-making without human intervention. Industry 4.0 integrates the physical and digital worlds, optimizing resource usage and increasing efficiency in production and management. The concept of Industry 5.0 introduces a new era focused on collaboration between humans and machines to create a more human-centric and sustainable working environment. Unlike Industry 4.0, which prioritizes automation and efficiency, Industry 5.0 highlights creativity, personalization, and sustainability. It leverages advanced technologies such as cognitive computing and robotics to foster close cooperation between humans and intelligent systems. The aim is to develop production processes that are not only efficient but also ethical and environmentally sustainable. Industry 5.0 places particular emphasis on sustainability and circular economy principles, such as waste reduction and efficient resource utilization. Smart factories utilizing renewable energy sources and recycling technologies are key aspects of this concept [1]. Additionally, Industry 5.0 promotes human-centered design and innovation, allowing consumers to receive products tailored to their specific needs. This approach not only improves product quality but also creates opportunities for creative expression and consumer satisfaction [2]. Industry 4.0 and Industry 5.0 represent distinct phases of technological development, emphasizing different focuses, roles of humans, technological applications, human-machine interactions, goals, sustainability, design approaches, integration of ethics and values, recycling technologies, and interaction modes. Industry 4.0 is centered on automation and efficiency in production processes, while Industry 5.0 highlights the humanization of technology and collaboration between humans and machines. In Industry 4.0, the role of humans is primarily limited to monitoring and maintaining automated systems, whereas in Industry 5.0, humans play an active role in creative processes and decision-making based on ethics [3].The use of technology in Industry 4.0 includes artificial intelligence, the Internet of Things (IoT), and big data analysis for process optimization. In contrast, Industry 5.0 introduces cognitive computing, personalization, and sustainability as key elements. Human-machine interaction in Industry 4.0 is characterized by minimal human intervention, with machines operating independently. However, Industry 5.0 emphasizes close collaboration between humans and machines to achieve creative and sustainable solutions. The goal of Industry 4.0 is maximum productivity and cost minimization, while Industry 5.0 focuses on sustainability, ethics, and user satisfaction.Sustainability, as a concept, is not a primary focus in Industry 4.0 but is a critical element in all stages of production in Industry 5.0. The design approach in Industry 4.0 is based on universal and standardized products, whereas Industry 5.0

aims for personalized products tailored to individual needs. Ethics and values are minimally integrated in Industry 4.0, while Industry 5.0 incorporates ethical principles, human values, and well-being into all aspects of production [4]. Recycling technologies have limited application in Industry 4.0 but play a central role in the circular economy of Industry 5.0. Interaction in Industry 4.0 is primarily technological, while Industry 5.0 combines technology with creative human engagement.A specific focus on the humanization of technology and human-machine collaboration reveals that in Industry 4.0, humans remain mostly in the background while machines take over the majority of processes. In contrast, Industry 5.0 emphasizes that machines complement humans rather than replace them. This concept enables creative expression, user satisfaction, and ethical design, where technology serves as a tool rather than a dominant force. Human-machine collaboration is not only technological but also creative and ethical, achieving a balance between productivity and humanity.Industry 5.0 represents a step forward in creating a world where technology serves humanity rather than the other way around. By combining advanced technological capabilities with human values and ethics, this concept has the potential to transform how we work, live, and communicate, laying the groundwork for a sustainable, inclusive, and humane future.

4. THE ROLE AND DEVELOPMENT OF INFORMATION SYSTEMS IN INDUSTRY 5.0

Industry 5.0 introduces the concept of personalized production while simultaneously emphasizing sustainability, requiring the use of advanced information systems. These systems leverage heterogeneous data sources, including sensors, IoT devices, and cyber-physical systems (CPS), to enable real-time data collection. Advanced algorithms for big data processing are utilized for the analysis and visualization of information, while technologies such as edge and cloud computing are integrated to optimize processing and storage. Information systems in Industry 5.0 feature modular software architectures based on microservices, providing high flexibility, scalability, and rapid adaptation to specific user requirements. Manufacturing Execution Systems (MES) are integrated with Enterprise Resource Planning (ERP) systems and Supervisory Control and Data Acquisition (SCADA) platforms to coordinate production lines and monitor performance.Software development in Industry 5.0 relies on several key technologies, which are shown in Table 1 [5],[6].

Table 1 Key Technologies for Software Development in Industry 5.0

Key Technology	Applications	Technical Components/Platforms
Artificial Intelligence (AI) and Machine Learning	Predictive maintenance (analyzing sensor data for early fault detection), production flow optimization (using reinforcement learning algorithms), and product personalization (clustering and recommendations).	TensorFlow, PyTorch for machine learning algorithms; OpenCV for computer vision; scikit-learn for data analysis.
Blockchain Technology	Ensuring data security through decentralized networks; tracking product origin in the supply chain.	Ethereum, Hyperledger, Corda.
Internet of Things (IoT)	Connecting devices to monitor production and working conditions in real time.	MQTT, CoAP, OPC UA for IoT communication; platforms like AWS IoT Core and Azure IoT Hub.
Cyber-Physical Systems (CPS)	Simulating production processes in digital twins for testing and optimization before implementation.	MATLAB/Simulink, Siemens MindSphere, Dassault Systèmes CATIA.
Real-Time Data Processing	Streaming data with Apache Kafka and RabbitMQ; real-time processing with Apache Flink.	Apache Kafka, RabbitMQ, Apache Flink.
Software Platform Integration	Integration of heterogeneous systems using REST API, GraphQL, gRPC.	IBM Watson for cognitive computing; Google Cloud ML Engine for machine learning; SAP Leonardo for business innovation.
Security and Sustainability	Data security ensured using AES and RSA algorithms; authentication with OAuth 2.0 and SAML. Sustainability achieved through energy-efficient IoT devices, renewable energy sources, and circular economy models.	AES, RSA for encryption; OAuth 2.0, SAML for authentication; energy-efficient IoT and renewable energy integration.

5. DIRECTIONS OF SOFTWARE DEVELOPMENT IN INDUSTRY 5.0

The directions of software development in Industry 5.0 emphasize the creation of human-centric software systems that foster seamless collaboration between humans and machines, promote sustainability by optimizing resource usage and reducing environmental impact, and apply circular economy principles to enable the reuse and repurposing of software components, contributing to a more efficient and eco-friendly technology ecosystem.

1.1. Human-Centric Software Systems

In Industry 5.0, software plays a crucial role in supporting collaboration between humans and machines, ensuring a seamless interaction where both can complement each other's strengths. Human-centric software systems are designed to enhance user experience by adapting to the needs and preferences of the user, creating intuitive interfaces and personalized solutions. These systems emphasize user empowerment, enabling efficient decision-making and fostering creativity. For example, software solutions aimed at improving user experience include adaptive interfaces in smart manufacturing systems, augmented reality (AR) tools for maintenance tasks, and personalized dashboards for real-time monitoring of production processes [7].

1.2. Sustainability in Software Development

Sustainability is a key principle in the development of software for Industry 5.0, with a focus on reducing environmental impact and optimizing resource usage. Ecologically friendly software approaches are being implemented to minimize energy consumption, optimize processing power, and extend the life cycle of software products. Recycling software components and reusing code not only reduces waste but also enhances efficiency. This approach aligns with the broader goals of reducing the carbon footprint of the technology sector. Resource optimization techniques, such as energy-efficient algorithms and cloud computing strategies, ensure that software operates sustainably, even as it scales [8].

1.3. Application of Circular Economy in Software Solutions

Software solutions in Industry 5.0 increasingly support the principles of circular economy, focusing on the continuous reuse and repurposing of resources. Circular economy principles are applied to software by creating systems that facilitate the efficient use of hardware, extend the lifespan of software products, and promote the reusability of software components. For example, software solutions that enable the tracking and management of product life cycles, monitor resource usage, and facilitate the repurposing of materials and components in manufacturing processes contribute to circular economic models. These applications not only help reduce waste but also optimize resource efficiency across the value chain [9].

2. ANALYSIS OF STRATEGIES AND LAWS OF THE REPUBLIC OF SERBIA IN THE DEVELOPMENT DIRECTIONS OF INFORMATION SYSTEMS FOR INDUSTRY 5.0

The Artificial Intelligence Development Strategy of the Republic of Serbia for the period 2020–2025 establishes a framework for advancing this field through several key goals and measures. These include the development of education tailored to the needs of modern society and the economy driven by the progress of artificial intelligence. This is achieved by improving educational content in primary and secondary schools, establishing minimum standards for the representation of artificial intelligence in higher education programs, and developing postgraduate study programs and professional training. Additionally, the strategy encompasses the advancement of science and innovation in the field of artificial intelligence and its applications, through support for researchers and innovations in priority areas, fostering collaboration between research institutions, the economy, and the public sector, and establishing an Institute for Artificial Intelligence(Figure 1). To promote an AI-driven economy, the

measures include supporting startup companies, small and medium enterprises, encouraging investments in artificial intelligence development, and establishing multisectoral development solutions in areas of public interest. Furthermore, improving the prerequisites for the development of artificial intelligence and public sector services is achieved through the establishment of an Artificial Intelligence Council, opening and reusing public sector data, developing mechanisms for reusing private sector data, creating shared infrastructure resources, and enhancing public sector services through the application of artificial intelligence[10].

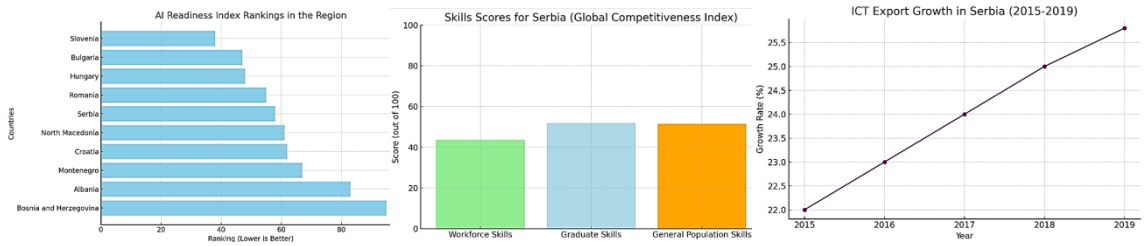

Figure 1 Regional AI Readiness, Serbia's Global Competitiveness, and ICT Services Export Growth (2015-2019)

The Strategy for the Development of Digital Skills in the Republic of Serbia for the period 2020–2024 represents a comprehensive approach to transforming society toward the digital economy and Industry 5.0. The primary goal of the strategy is to enhance digital literacy through the synergy of educational, technological, and economic reforms (Figure 2). It highlights that 51% of Serbia's population lacks basic digital skills, underscoring the urgent need for systematic investments in educational programs and digital infrastructure. Special emphasis is placed on advancing education in information technology by introducing informatics as a subject in primary schools and continuously increasing the number of enrolled students in the IT sector, which has seen an annual growth rate of 4%, aligning with the rising global demand for digital professionals. The strategy is aligned with the European Union's guidelines, such as "Europe 2020," and underscores the necessity for cross-sectoral collaboration to improve digital capacities, particularly in e-government, e-business, and cybersecurity. The growth of the domestic IT market, which reached €522 million in 2018, alongside the increasing number of innovative startups, confirms Serbia's potential as a regional leader in digital transformation. Additionally, the strategy acknowledges the importance of reducing the digital divide between urban and rural areas and ensuring the inclusion of marginalized groups, thereby establishing a foundation for sustainable and inclusive development in line with the global sustainability goals outlined in the 2030 Agenda [11].

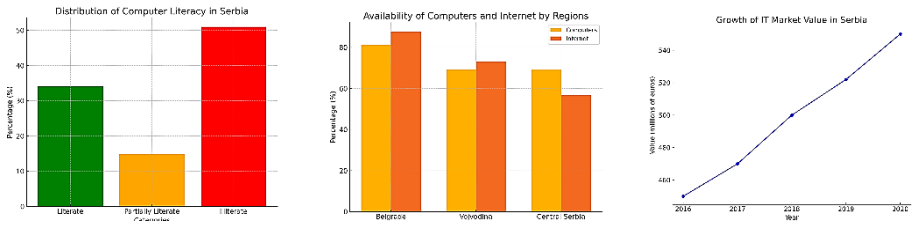

Figure 2 Distribution of Computer Literacy in Serbia, Availability of Computers and Internet by Regions and Growth of IT Market Value in Serbia(2015-2019)

Industry 5.0 introduces a paradigm that integrates artificial intelligence, automation, and human creativity to enhance production processes and create sustainable business models. In the context of the Industrial Policy Strategy of the Republic of Serbia (2021–2030), digitalization and artificial intelligence have been identified as key factors for industry transformation. Proposed measures, such

as the introduction of digital platforms, the promotion of collaboration between the IT sector and traditional industries, and the establishment of innovation hubs, directly support the vision of Industry 5.0 (Figure 3). These activities, combined with increased investments in research and development, provide a foundation for enhancing the competitiveness of the domestic economy in the global market [12].

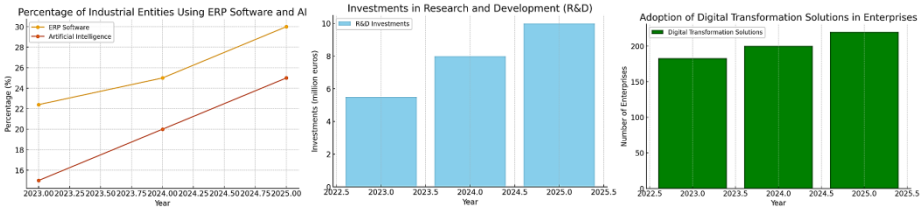

Figure 3 Percentage of Industrial Entities Using ERP Software and AI, Investments in Research and Development (R&D) and Adopting of Digital Transformation Solutions in Enterprises

3. FUTURE DIRECTIONS OF INFORMATION SYSTEMS DEVELOPMENT IN INDUSTRY 5.0

The development of information systems (IS) in Industry 5.0 focuses on integrating advanced technologies such as AI, IoT, AR, VR, quantum computing, and big data analytics to achieve sustainability, ethics, and innovation. IS will optimize business processes, reduce resource consumption, and improve energy efficiency. Big data enables precise ecological tracking, while AR and VR enhance efficiency through interactive visualizations and real-time monitoring. Quantum computing advances real-time data processing, unlocking potential in medicine, finance, and environmental protection. User-adaptable interfaces and IoT-driven automation will prioritize sustainability and ethical design, preserving jobs by enhancing human capabilities. These technologies drive long-term development, productivity, and environmental preservation [5],[10].

4. CONCLUSION

The development of information systems in the context of Industry 5.0 offers transformative potential for creating a more sustainable and human-centered industrial future. By integrating advanced technologies such as artificial intelligence, IoT, and blockchain, industries can achieve enhanced collaboration between humans and machines, optimize resource usage, and adhere to circular economy principles. The shift towards human-machine cooperation in Industry 5.0 not only improves production efficiency but also emphasizes the importance of ethical design and environmental responsibility. Serbia's AI development strategy positions the nation to embrace these changes, contributing to both technological and ethical advancements in the global industrial landscape. Moving forward, continued research and innovation will be essential in addressing the challenges of implementing Industry 5.0 and ensuring its successful integration into modern industries.

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