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THE IMPLEMENTATION OF INDUSTRY 4.0 CONCEPT IN SMART CITY

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Purpose: The purpose of this publication is to present relations between Industry 4.0 and Smart City.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The study highlights the positive effects of Industry 4.0 on Smart Cities, including efficient infrastructure, connected transportation, data-driven decision-making, improved public services, and enhanced safety and security. Furthermore, Industry 4.0 supports sustainability, economic growth, and resilience in Smart Cities. However, implementing Industry 4.0 in Smart Cities poses challenges such as high costs, data security and privacy concerns, digital divide issues, workforce displacement, and technological complexity. Interoperability, energy consumption, lack of standardization, overreliance on technology, and resistance to change are also potential hurdles to be addressed.
Originality/value: Detailed analysis of all subjects related to the problems connected with the smart city in Industry 4.0.

Keywords: smart city, Industry 4.0, digitalization, sustainability, economy, public services.

Category of the paper: literature review.

1. Introduction

A smart city is a visionary urban concept that harnesses cutting-edge technology and data to enhance the quality of life for its residents and optimize resource management. It seeks to create a more efficient, sustainable, and interconnected urban environment.

In a smart city, various devices, sensors, and systems are integrated into the urban infrastructure to collect real-time data on various aspects such as traffic flow, energy consumption, waste management, and air quality. This data is then analyzed and used to make informed decisions to improve city services and solve challenges (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021; Orzeł, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Steculа, Wolniak, 2022; Olkiewicz et al., 2021).

Industry 4.0, also known as the Fourth Industrial Revolution, is a transformative concept that represents the integration of advanced technologies into the manufacturing and industrial sectors. It leverages cutting-edge technologies like the Internet of Things (IoT), artificial intelligence (AI), big data, cloud computing, and robotics to create smart, connected, and automated production systems (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021).

The core idea of Industry 4.0 is to create a highly efficient, flexible, and autonomous manufacturing ecosystem. Machines and equipment in factories are equipped with sensors that gather real-time data on their performance and processes. This data is then analyzed and used to optimize production, predict maintenance needs, and improve overall productivity (Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023; Wolniak, 2013, 2016; Hys, Wolniak, 2018).

Industry 4.0 empowers smart cities with advanced technologies and data-driven approaches, leading to increased efficiency, sustainability, and citizen satisfaction. The integration of Industry 4.0 concepts into urban planning and governance is pivotal in shaping the cities of the future, where technology and innovation work harmoniously to create a better living environment for all.

The purpose of this publication is to present relations between Industry 4.0 and Smart City.

2. Smart city

Citizens in a smart city benefit from advanced transportation systems that promote seamless mobility, such as intelligent traffic management and public transportation options. Additionally, the concept promotes smart grids and renewable energy sources to ensure efficient energy distribution and reduce environmental impact. Smart city initiatives often involve digital platforms and applications that engage citizens in governance, making it easier for them to access services and participate in decision-making processes. These platforms can include apps

for reporting issues, accessing public services, or staying informed about city events and developments (Herdiansyah, 2023).

Safety and security are also key components of a smart city, with the integration of surveillance technologies and emergency response systems to ensure quick and effective responses to incidents. Ultimately, a smart city aims to create a more sustainable and connected urban landscape that enhances the well-being of its residents while minimizing environmental impact and optimizing resource utilization.

In a smart city, technology acts as a backbone that connects various aspects of urban life, allowing for real-time monitoring, data analysis, and predictive modeling. Smart cities emphasize the development of robust digital and physical infrastructure. This includes high-speed internet access, a network of sensors and actuators, and the installation of smart grids to efficiently manage utilities like electricity, water, and gas (Embarak, 2022).

Environmental sustainability is a core principle of smart cities. The integration of renewable energy sources like solar and wind power, energy-efficient buildings, and optimized waste management systems help reduce carbon footprints and ensure a cleaner environment. Smart cities aim to improve transportation efficiency and reduce traffic congestion. This involves implementing intelligent traffic management systems, promoting the use of electric vehicles, and providing better public transportation options. Additionally, bike-sharing and pedestrian-friendly infrastructure contribute to a greener and healthier urban environment (Samarakkody et al., 2022).

The heart of a smart city lies in the data it collects and analyzes. Data is gathered from sensors, IoT devices, and various digital platforms. Advanced data analytics and machine learning algorithms help city officials make informed decisions, optimize resource allocation, and respond proactively to changing urban needs. Smart cities encourage active citizen participation and engagement. Digital platforms and mobile apps enable residents to access government services, report issues, provide feedback, and participate in civic activities. This creates a more inclusive and transparent governance structure (Albino et al., 2015).

Smart cities integrate technology into healthcare and public service delivery. Telemedicine, remote health monitoring, and smart clinics improve healthcare accessibility and reduce the burden on healthcare facilities. Additionally, smart public services like waste management and street lighting ensure more efficient resource utilization. Utilizing advanced surveillance systems, smart cities can enhance safety and security. Integrated networks of cameras and sensors enable real-time monitoring of public spaces, improving emergency response times and aiding law enforcement efforts (Lara et al., 2016).

The smart city concept fosters an environment for innovation and entrepreneurship. It attracts businesses and investment by offering a tech-savvy ecosystem, encouraging startups, and supporting research and development initiatives. Smart cities are better equipped to handle disasters and emergencies. Through data analysis and modeling, they can predict potential risks and plan mitigation strategies, ensuring a more resilient urban infrastructure. Also the smart

city concept is designed to enhance the overall quality of life for its inhabitants. By creating efficient, sustainable, and interconnected urban spaces, smart cities aim to provide a better standard of living, improved accessibility to resources, and greater opportunities for growth and development (Dameri, 2016).

3. Industry 4.0

The concept emphasizes the interconnectivity of devices and systems, creating a "smart factory" where machines can communicate with each other, make decentralized decisions, and adapt to changing conditions without human intervention. This connectivity allows for seamless information flow throughout the production process, facilitating better coordination and resource allocation (Adel, 2022).

Industry 4.0 also focuses on customization and personalization of products. With the integration of advanced technologies, manufacturers can efficiently produce small batches of customized goods at costs comparable to mass production. This enables businesses to meet the individual needs and preferences of customers, fostering customer satisfaction and loyalty (Wolniak, Sułkowski, 2015, 2016; Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022).

Moreover, the concept drives innovation and new business models. By harnessing the power of data analytics, companies can gain insights into market trends, consumer behavior, and product performance, leading to better-informed strategic decisions and opportunities for new revenue streams. However, as Industry 4.0 involves extensive automation and digitization, there are challenges to address, including cybersecurity risks, data privacy concerns, and the need to reskill the workforce for jobs that require a higher level of technical expertise (Akundi et al., 2022).

Industry 4.0 represents a significant shift in the manufacturing landscape, offering increased efficiency, agility, and competitiveness to businesses while shaping a new era of intelligent and technology-driven industries (Olsen, 2023).

Industry 4.0 relies on the integration of physical machines and digital systems, creating cyber-physical systems. These systems are equipped with sensors, actuators, and communication devices that enable them to collect and exchange data in real-time. As a result, manufacturing processes become more adaptive, responsive, and self-optimizing. The IoT plays a crucial role in Industry 4.0 by enabling the seamless connection and communication of various devices and assets. Machines, products, and even individual components can be equipped with IoT sensors, facilitating continuous data exchange and enabling remote monitoring and control (Aslam et al., 2020).

The massive amounts of data generated by cyber-physical systems and IoT devices are processed and analyzed through advanced data analytics techniques. This data-driven approach empowers manufacturers to make data-informed decisions, optimize processes, detect anomalies, and predict maintenance needs, leading to higher efficiency and reduced downtime. AI algorithms are used in Industry 4.0 to extract meaningful insights from data, identify patterns, and make autonomous decisions. Machine learning models can analyze historical data to predict future events, optimize production schedules, and improve quality control (Bakir, Dahlan, 2022).

Cloud-based platforms provide the infrastructure needed to store and process the vast amounts of data generated by Industry 4.0 technologies. Cloud computing offers scalability, accessibility, and cost-effectiveness, enabling businesses of all sizes to adopt and benefit from advanced technologies. Industry 4.0 encourages the adoption of additive manufacturing techniques, like 3D printing, to enable rapid prototyping, on-demand production, and greater design flexibility. This can lead to reduced waste, lower inventory costs, and faster product development cycles (Cillo et al., 2022).

While Industry 4.0 emphasizes automation, it also recognizes the importance of human involvement in the manufacturing process. Humans and machines collaborate to complement each other's strengths, with workers focusing on complex problem-solving, creativity, and decision-making, while robots handle repetitive and dangerous tasks. Industry 4.0 extends its benefits beyond individual factories by integrating the entire supply chain. Real-time data sharing and transparency allow for better coordination among suppliers, manufacturers, and distributors, leading to a more agile and responsive supply chain ecosystem. The concept of Industry 4.0 promotes sustainable practices in manufacturing, such as energy efficiency, waste reduction, and eco-friendly materials. Smart monitoring and optimization tools help reduce the environmental impact of industrial processes. Industry 4.0 has far-reaching implications on a global scale. Countries and companies that embrace these technologies gain a competitive edge in the global market. It fosters innovation, enhances productivity, and opens up new business opportunities (Di Marino et al., 2023).

Industry 4.0 represents a paradigm shift in manufacturing, revolutionizing traditional industries and paving the way for a new era of intelligent, interconnected, and data-driven manufacturing processes. Its potential to improve efficiency, innovation, and sustainability makes it a transformative force across various sectors worldwide. However, it also requires careful consideration of ethical, security, and social aspects to ensure its responsible implementation and maximize its positive impact (Ghibakholl et al., 2022).

4. Smart city and Industry 4.0

Industry 4.0, with its focus on advanced technologies and data-driven processes, has a significant impact on smart cities, transforming the way urban environments are managed and improving the quality of life for residents. Smart cities leverage Industry 4.0 technologies to create more efficient infrastructure. Intelligent sensors and IoT devices are integrated into urban systems such as transportation, energy grids, and waste management, enabling real-time data collection and analysis. This data-driven approach allows for optimized resource allocation, reduced energy consumption, and better management of city services (Javaid, Haleem, 2020).

Industry 4.0 enhances transportation in smart cities. Smart traffic management systems use real-time data to optimize traffic flow, reduce congestion, and minimize travel time. Connected vehicles, equipped with IoT devices, can communicate with each other and with infrastructure, enabling safer and more efficient transportation. Also Industry 4.0 enables smart cities to implement advanced energy management systems. Smart grids and energy distribution networks use data analytics to balance energy supply and demand efficiently. This leads to reduced energy wastage, lower emissions, and increased use of renewable energy sources, contributing to a greener and more sustainable city (Javaid et al., 2020).

Smart cities benefit from the data-driven decision-making capabilities of Industry 4.0. Real-time data on various aspects of the city's functioning, such as air quality, waste generation, and public services utilization, help city authorities make informed decisions and respond proactively to emerging challenges and opportunities. Industry 4.0 enables the development of smart public services in smart cities. Citizens can access government services through digital platforms, report issues through mobile apps, and stay informed about city developments through connected devices. This seamless integration improves service delivery and enhances the overall citizen experience (Johri et al., 2021).

Describe concept contribute to improved safety and security in smart cities. Advanced surveillance systems, including AI-based video analytics, can monitor public spaces and detect potential security threats. Emergency response systems are also enhanced, enabling faster and more effective responses to incidents. By optimizing resource utilization and reducing energy consumption, Industry 4.0 supports sustainable urban living in smart cities. The concept promotes eco-friendly practices, waste reduction, and green infrastructure development, ensuring a healthier environment for residents.

The integration of Industry 4.0 technologies attracts businesses and investors to smart cities. The tech-savvy environment encourages innovation, entrepreneurship, and the development of new business models. This, in turn, boosts economic growth and creates job opportunities for the local workforce. Smart cities equipped with Industry 4.0 capabilities are more resilient to disasters and emergencies. Predictive analytics and modeling can help anticipate potential risks

and plan effective mitigation strategies, enhancing the city's ability to withstand and recover from adverse events.

In table 1 there is an comparision of Smart City and Industry 4.0.

Table 1.
Comparison between Smart city and Industry 4.0

Aspect	Smart City	Industry 4.0
Focus	Urban development and city management	Manufacturing and industrial transformation
Technology Emphasis	IoT, AI, big data, connectivity, digital platforms	IoT, AI, big data, cloud computing, automation
Objective	Enhance urban living, sustainability, efficiency	Optimize manufacturing processes, increase productivity
Data Utilization	Real-time data for city services and decision-making	Real-time data for production optimization and decision-making
Infrastructure	Smart grids, connected transportation, public services	Cyber-physical systems, smart factories, connected machinery
Citizen Engagement	Digital platforms for access to services and participation	Human-machine collaboration in manufacturing
Impact Areas	Transportation, energy, waste management, safety	Production efficiency, quality, supply chain
Scalability	Applicable to cities of various sizes and contexts	Applicable to diverse manufacturing industries
Resilience	Disaster management, emergency response	Predictive maintenance, adaptive manufacturing
Economic Implications	Attracting businesses, boosting local economy	Fostering innovation, creating new business models

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Cillo et al., 2022; Di Marino et al., 2023; Javaid et al., 2020; Johri et al., 2021; Herdiansyah, 2023; Embarak, 2023; Albino et al., 2015; Lara et al., 2016; Dameri, 2016).

In the table 2 there is an analysis of potential positive impact of Industry 4.0 on various smart city activities. Industry 4.0 brings numerous benefits to Smart Cities by making them more efficient, connected, and sustainable while improving the lives of their residents through better services and safety measures.

Table 2.
Factors of positive impact of Industry 4.0 on Smart City concept

Factor	Description
Efficient Infrastructure	Industry 4.0 technologies optimize urban systems, such as transportation, energy grids, and waste management, leading to better resource allocation and reduced energy consumption.
Connected Transportation	Smart cities benefit from Industry 4.0 advancements in transportation, such as intelligent traffic management, connected vehicles, and data-driven decision-making, resulting in reduced congestion and improved mobility.
Data-Driven Decision Making	Industry 4.0 enables smart cities to make data-informed decisions based on real-time data collected from various urban services and processes, leading to better planning and resource management.
Improved Public Services	The integration of Industry 4.0 technologies improves public service delivery in smart cities, offering citizens seamless access to government services through digital platforms and mobile apps.

Cont. table 2.

Enhanced Safety and Security	Industry 4.0 contributes to better safety and security in smart cities through advanced surveillance systems, AI-based video analytics, and improved emergency response capabilities.
Sustainable Urban Living	With Industry 4.0 optimizing resource utilization and reducing energy consumption, smart cities can achieve greater sustainability and foster eco-friendly practices and green infrastructure development.
Economic Growth and Innovation	Industry 4.0 attracts businesses and investors to smart cities, creating an innovative environment that fosters entrepreneurship, economic growth, and new business models.
Resilience and Disaster Management	Smart cities with Industry 4.0 capabilities are more resilient to disasters and emergencies, thanks to predictive analytics and modeling, which aid in effective risk mitigation and recovery strategies.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Cillo et al., 2022; Di Marino et al., 2023; Javaid et al., 2020; Johri et al., 2021; Herdiansyah, 2023; Embarak, 2023; Albino et al., 2015; Lara et al., 2016; Dameri, 2016).

The table 3 outlines the potential problems that may arise when implementing Industry 4.0 technologies in a Smart City.

Table 3.
Problems of implementing Industry 4.0 on Smart City

Problem	Description
High Implementation Costs	Integrating Industry 4.0 technologies can be expensive, requiring significant upfront investments in infrastructure, training, and technology upgrades.
Data Security and Privacy Concerns	Industry 4.0 relies heavily on data collection and sharing, raising concerns about data security, privacy breaches, and unauthorized access to sensitive information.
Digital Divide and Accessibility	Not all residents may have equal access to digital technology, creating a digital divide that could leave certain segments of the population underserved or excluded.
Workforce Displacement	Automation and AI in Industry 4.0 could lead to job displacement for certain workers, particularly in traditional manufacturing and service sectors.
Technological Complexity	Implementing and managing complex Industry 4.0 systems may require a highly skilled workforce, leading to challenges in finding and retaining qualified personnel.
Interoperability Issues	Different Industry 4.0 technologies may not always be fully compatible with each other, causing challenges in achieving seamless integration and communication.
Energy Consumption and Environmental Impact	The increased use of advanced technologies in Industry 4.0 could lead to higher energy consumption and potentially increase the carbon footprint of the city.
Overreliance on Technology	Relying heavily on technology could lead to vulnerabilities, as a single point of failure or cyberattack could disrupt critical services and infrastructure.
Lack of Standardization	A lack of standardized protocols and practices in Industry 4.0 could hinder interoperability and create complexities in the development and deployment of smart city solutions.
Resistance to Change	Resistance from various stakeholders, including government agencies, businesses, and citizens, may slow down the adoption of Industry 4.0 solutions in the smart city context.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Cillo et al., 2022; Di Marino et al., 2023; Javaid et al., 2020; Johri et al., 2021; Herdiansyah, 2023; Embarak, 2023; Albino et al., 2015; Lara et al., 2016; Dameri, 2016).

5. Conclusion

The paper discusses the concept of a Smart City and the transformative influence of Industry 4.0 on urban development. A Smart City aims to enhance residents' quality of life and resource management by utilizing cutting-edge technology and real-time data. It integrates various devices, sensors, and systems to monitor and analyze aspects such as traffic flow, energy consumption, waste management, and air quality. Industry 4.0, known as the Fourth Industrial Revolution, revolutionizes manufacturing by integrating advanced technologies like IoT, AI, big data, and robotics. It aims to create efficient, flexible, and autonomous manufacturing systems, optimizing production and predictive maintenance through data analysis.

The paper highlights the positive impacts of Industry 4.0 on Smart Cities, such as efficient infrastructure, connected transportation, data-driven decision-making, improved public services, and enhanced safety and security. Industry 4.0 also promotes sustainability, economic growth, and resilience in Smart Cities. However, the implementation of Industry 4.0 in Smart Cities also poses challenges, including high costs, data security and privacy concerns, digital divide and accessibility issues, workforce displacement, and technological complexity. Interoperability, energy consumption, lack of standardization, overreliance on technology, and resistance to change are also potential problems that need to be addressed. The integration of Industry 4.0 technologies in Smart Cities offers numerous benefits, but it requires careful planning and management to overcome potential challenges and ensure responsible and effective implementation for the betterment of urban living.

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